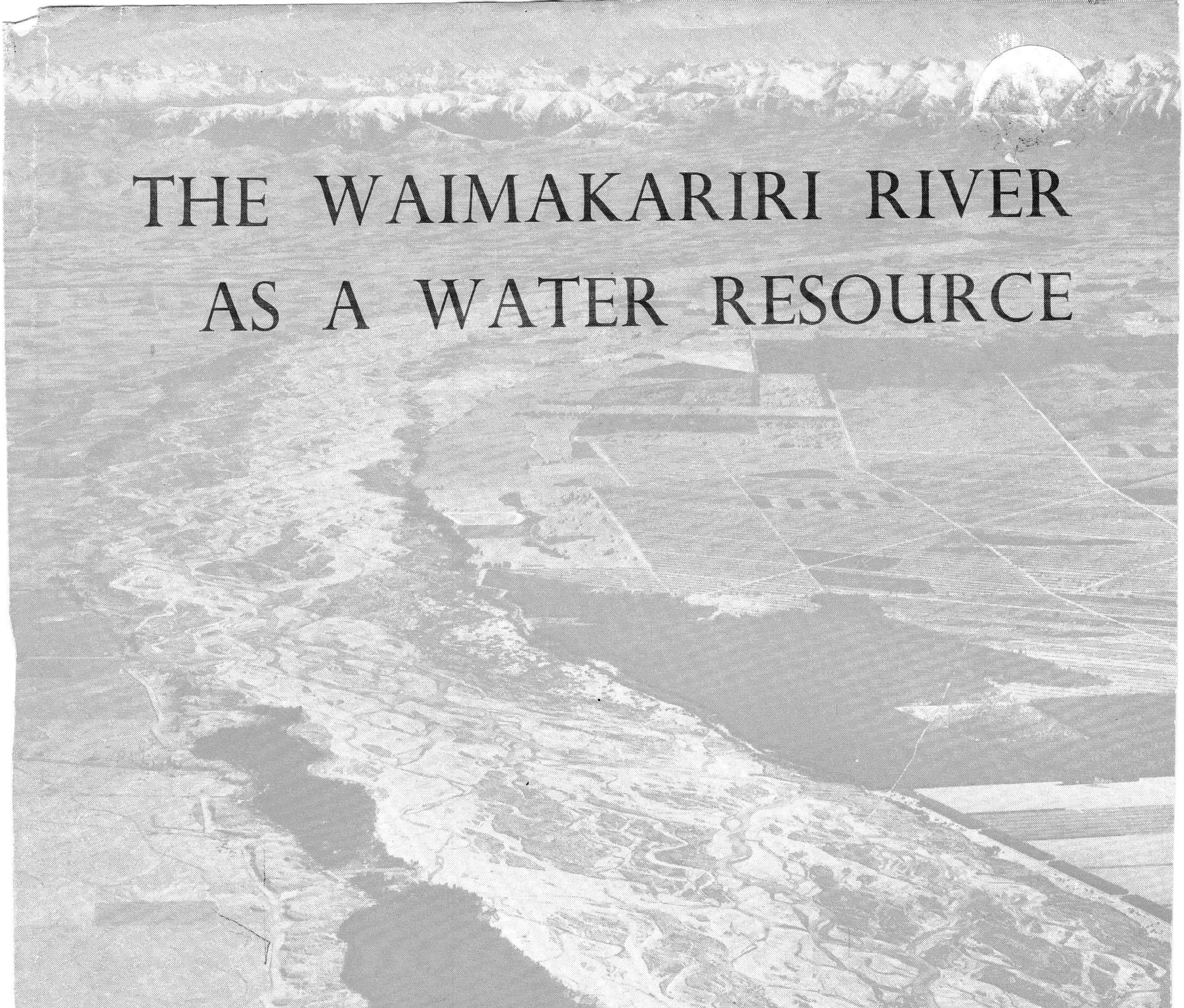

THE WAIMAKARIRI RIVER AS A WATER RESOURCE

ERLE B. DALMER

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By

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A Report presented to
THE NORTH CANTERBURY CATCHMENT BOARD
ON 2 OCTOBER, 1970

Published by
THE NORTH CANTERBURY CATCHMENT BOARD
CHRISTCHURCH NEW ZEALAND
1971

Cover photograph by V. C. Browne

PRINTED AT THE CAXTON PRESS
Christchurch New Zealand

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SUMMARY

A survey has been made of the Waimakariri River as a water resource. All known flow data were recorded and certain flow duration curves drawn. The only abstractions of consequence are between the Gorge Bridge and Halkett to supply three stock water systems, which take about one tenth of the low flow. The river water at normal flows is of high quality down as far as Wright's Cut, but downstream of the cut the river is polluted by industrial wastes transported by the South Branch and the Kaiapoi River. The major use of the river by industry is thus for dilution of polluted industrial discharges in the four miles nearest the sea. An indication is given of the extent of this pollution.

Over the past century river diversions were made and control schemes carried out to prevent overflows and to reduce bank erosion. The river is still aggrading in the lower reaches.

A quantitative assessment is given of infiltration in the three miles between Halkett and West Melton Road Groyne.

1. INTRODUCTION

In January 1970 an examination of the Waimakariri River as a water resource was commenced. Regional Water Boards are authorised to investigate and record all significant resources of natural water under the Water and Soil Conservation Act 1967.* Early in the year representatives of the Board had discussions on irrigation with the Waimakariri Ashley Irrigation Committee at Cust and with the Northern Central Plains Irrigation Committee at Darfield. On 6 March the Board resolved to advise the Waimakariri Ashley Irrigation Committee that the Board is continuing its investigation of the water resources of the Waimakariri River in order that it may be in a position to give a decision in due course following the receipt of a formal application to divert and take water for irrigation. On 13 March the District Commissioner of Works advised that representations had been made to the Minister asking for a study of irrigation potential, and that the Minister would like to receive from the Board a report on what water might be available for irrigation. The District Commissioner of Works offered to assist in the preparation of the report. On 10 April the Board thanked the Ministry of Works for

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* Section 20 of the Water and Soil Conservation Act 1967 contains the following references:

S.20(5). Every Regional Water Board shall have the following additional functions, rights, powers, and duties:

(e) Subject to directions of the Authority, the Board shall investigate and record all significant resources of natural water within the region, and its quality and availability, and shall check so far as possible upon the effects of damming, abstractions, diversions, pollutions, and other factors affecting the volume, quality, and availability of natural water above and below ground within the region, and shall direct the attention of the Authority to all important problems and needs in respect of natural water:

(f) As directed from time to time by the Authority, the Board shall collect, sort, and record data on resources and availability of natural water, and shall supply to public authorities and the public information so collected:

(g) The Board shall from time to time obtain and apply the directions of the Pollution Advisory Council and the Water Allocation Council in respect of natural water within the region, and in respect of the classification and quality control of all natural water within the region:

S.20(6). Every Regional Water Board shall have due regard to recreational needs and the safeguarding of scenic and natural features, fisheries, and wildlife habitats, and shall consult the appropriate authority controlling fisheries and wildlife where they are likely to be affected.

the offer of assistance and advised that it would be some three months before a report could be presented.

The Board met the Irrigation Committee of the Water Allocation Council in Christchurch on 6 April 1970 and commented upon submissions which it had previously supplied at the request of the Council. The Board's submission No. 4 gave its views on the principles applicable to the granting of water rights, and suggested that the water resource had first to be established, and then the available water had to be allocated in some order of priority to competing interests. It was stated at that meeting, in answer to a question from the Committee, that the Board was not able at that moment to allocate any particular share of the Waimakariri water resource to irrigation.

2. THE RIVER

The Waimakariri has an upper catchment of 950 square miles above the Gorge Bridge, drains a length of 31 miles of the Alps, and floods principally from westerly or north-westerly rains falling within a few miles of the main divide.

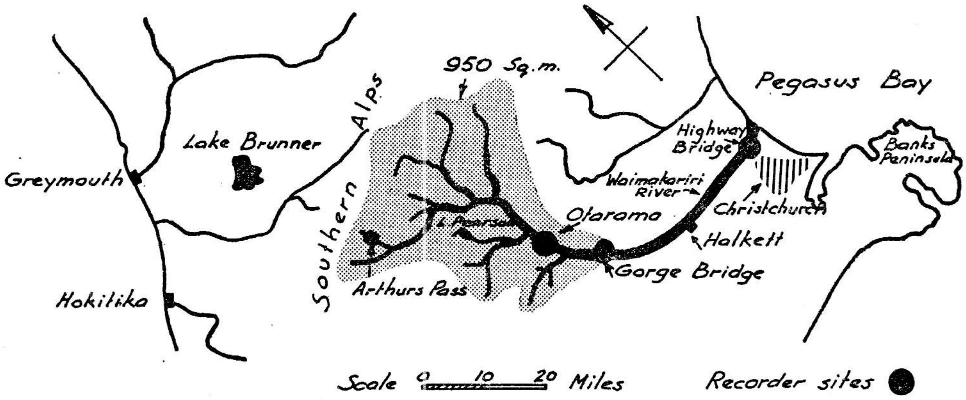

Figure 1: THE WAIMAKARIRI RIVER AND THE UPPER CATCHMENT

The river length is 85 miles and the total catchment exceeds 1400 square miles. It is a mountain torrent for most of its course, with a steep slope flattening out in the lower ten miles, where aggradation becomes a problem. The channel is wide and braided, except where confined in the gorge, and the average slope across the plain from the Gorge Bridge to Dixon's Bay is about 24 feet to the mile. The larger tributaries are the Poulter, Bealey, Hawdon and Esk, which rise in major flood on the rare occasions when precipitation of the order of 8 to 12 inches occurs in less than 24 hours. Such floods interfere with road and rail communications and cause erosion or overflow in the 20 miles from Halkett to the sea. The menace of the river to Christchurch was fully appreciated at an early stage of settlement. 'In colonizing the country we must civilize the river' was editorial comment in 1869 upon the first reports, that the Waimakariri was threatening to overflow at Rowley's. The river was still building up its flood plain in 1850 when its north and south branches were enveloping Kaiapoi Island, and at that time it might just as easily have been following the course of the Avon through Christchurch, discharging north into the Rangiora 7000 acre swamp, or even flowing south into

Lake Ellesmere. The accidents of time and place thus determined the course of settlement, the position of Christchurch, and the general route within which the river had to be constrained.

The river is deeply entrenched for some 30 miles through the gorge down to the Gorge Bridge and for another 16 miles to Halkett, so that overflows are only possible from Halkett downstream. The principal problem of control in this river is the tendency for the bed to aggrade in the lower reaches, causing a reduction in flood discharge capacity. At about 11 miles from the coast the slope of the river gradually decreases downstream, and it is over this length below 11M that significant increases have been observed in mean bed level. These increases are due to shingle moving down the channel from upstream, but the proportions contributed from bank erosion and from channel degradation are not known. Any proposal to use the Waimakariri must take into account shingle movement and the problem of sediment control, the solution of which is still an open question.

3. STAGE RECORDS

Continuous records of river level have been taken as follows:

(a) Otarama No. 1,

from 1/6/23 to 10/9/36, 23/11/37 to 27/2/40. These records were obtained by the Municipal Electricity Department of the Christchurch City Council, and are held by the Board.

(b) Otarama No. 2,

from 6/9/61 to date. This is a Ministry of Works gauge on the same site as Otarama No. 1 (site No. 66403), and charts are changed by the Board fortnightly.

(c) Old Gorge Gauge,

from 13/3/29 to 31/12/59, but charts were not changed regularly during war years. The recorder is on the left bank just east of the bridge.

(d) New Gorge Gauge,

from 7/8/57 to date. This is on the left bank three chains downstream from the old gorge gauge, at site No. 66402.

(e) New Recorder Highway Bridge,

from 10/11/64 to date. This is on the right bank just upstream of the bridge, at site No. 66401.

These recorder sites are shown in Figure 1. Certain records were also taken by the Waimakariri River Trust at White's Bridge and at the Highway Bridge, but these did not all survive the 1935 fire.

4. PRECIPITATION

4.1 Rainfall Records:

Annual precipitation at Arthur's Pass, from 1923 to 1952 at the railway station, and from 1954 to 1969 at the store, is noted in Appendix C, which also states what records are held by the Board. Other records are kept by the New Zealand Meteorological Service, by the New Zealand Forest Service for a number of rain-gauges in the Craigieburn range, and by the University of Canterbury for a gauge at Cass. The Board also holds certain records of monthly rainfall at Otira, Bealey, Arthur's Pass, and Mt. Torlesse, for broken periods. The locations of gauges in the upper catchment are shown on Figure 2.

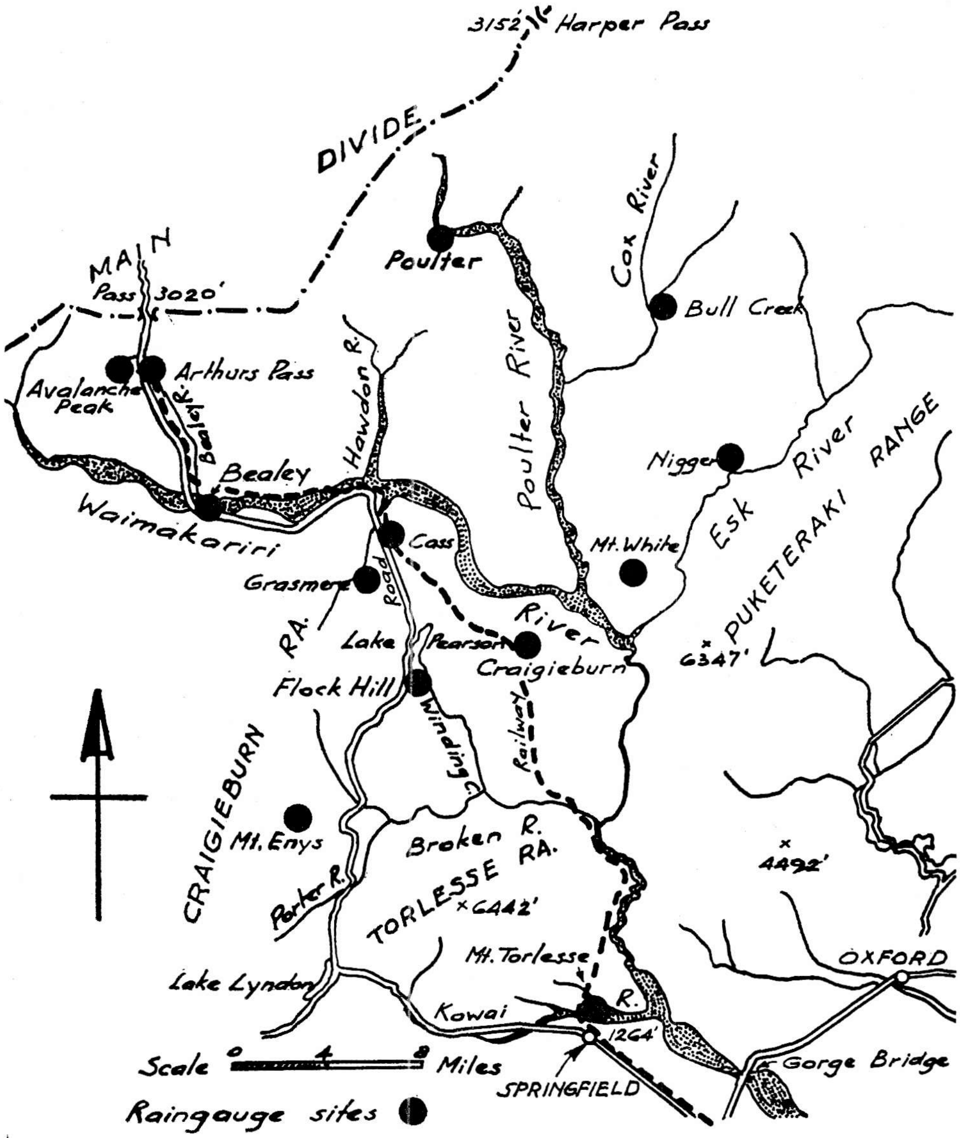

Figure 2: RAINGAUGE SITES

4.2 Annual precipitation:

Average annual rainfalls at nine stations in the upper Waimakariri catchment are given in Table 1.

4.3 Rainfall and river flow:

Figure 3 shows monthly precipitation at Arthur's Pass store and monthly mean discharges through Wright's Cut for the three years 1967 to 1969. This comparison ignores the effect of rainfall in all other parts of the catchment, but it can be seen that river flows follow generally the pattern of rainfall at Arthur's Pass.

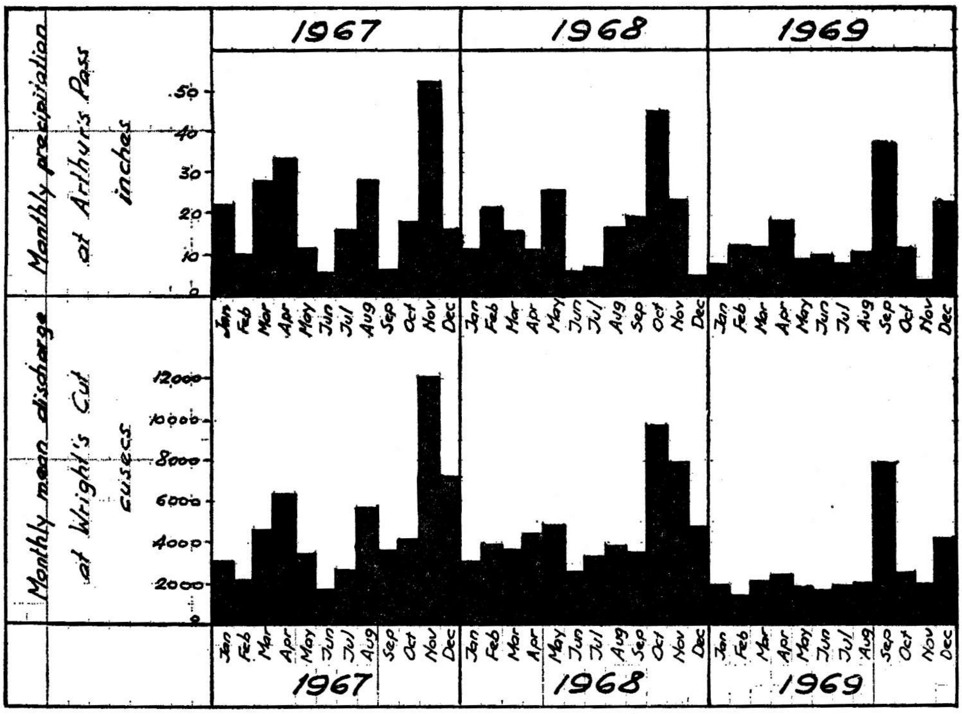

Figure 3: MONTHLY MEAN DISCHARGE AT WRIGHT'S CUT AND MONTHLY PRECIPITATION AT ARTHUR'S PASS

Table 1: AVERAGE ANNUAL PRECIPITATION

Location	*Period*	*Term (years)*	*Rainfall (inches)*
Arthur's Pass (store)	1954/69	16	184
Avalanche Peak	1960/61	2	117
Poulter	1960/61	2	113
Bealey 1928-1936, 1956-62, 1964-67	various	20	66
Bull Creek	1965/69	5	57
Grasmere 1945-1949, 1952-1967	various	21	49
Nigger	1962/69	8	43
Mt. White between 1923 and 1946	various	20	40
Craigieburn Station	1923/43	21	36

4.4 Snow:

Snow has not been considered an important factor compared with rainfall in producing Waimakariri floods. Wood (1933) commented that although the river is to a great extent snow fed 'the influence of the melting snow in the flood discharge is not very great, the big flood being mainly due to heavy rains from the West Coast'. The little evidence available indicates that snow melt increases the average flow in the river from September to November, and possibly into December.

The only published work on snow in the Waimakariri catchment is by Morris

and O'Loughlin (1965), and the following notes and comments are all taken from their paper on 'Snow Investigations in the Craigieburn Range'. These investigations were carried out between 1962 and 1964 while they were testing snow survey techniques. They were not attempting to assess the water equivalent of the snow pack over the catchment or to measure total winter precipitation. They recorded depth and density on snow courses at 5600 ft. and at 4700 ft. The total annual accumulation at 5600 ft. averaged 20 ins. water equivalent and at 4700 ft. only 5 ins. Their work is summarised in Table 2.

Table 2: SNOW INVESTIGATIONS CRAIGIEBURN RANGE
(after Morris and O'Loughlin pp. 10 and 14)

		ACCUMULATION			*THAW*		
Location	*Year*	*Period*	*Days*	*Water equiv. (ins.)*	*Period*	*Days*	*Water equiv. (ins.)*
ALAN'S	1962	17 July—4 Oct.	79	15.69			
BASIN	1963	31 May—10 Sept.	102	22.17	10 Sept.—4 Nov.	55	17.58
5600'	1964	5 June—8 Oct.	125	22.80	8 Oct.—25 Nov.	48	16.90
CAMP	1962	1 Aug.—5 Sept.	35	1.91			
STREAM	1963	27 June—9 Sept.	74	5.55	9 Sept.—2 Oct.	24	8.20
4700'	1964	4 June—8 Oct.	126	7.60	8 Oct.—15 Nov.	27	9.50

It would appear that in the thaw water stored over the winter as snow is gradually released over a period of one or two months, that from 5600 ft., about 17 inches is released, and about half that from 4700 ft. It is suggested in the paper at p. 16 that total precipitation in the upper Broken River basin is of the order of 80 ins. annually, of which probably on all sites above 5000 ft. approximately one third falls as snow; that below 5000 ft. and down to 3000 ft. the importance of snow decreases; and that at the 3000 ft. level the contribution of snow to total precipitation is negligible.

5. DISCHARGE

5.1 Definitions:

Discharges in this report are in cubic feet per second, or cusecs.

Daily mean discharge is the *mean* flow over a period of 24 hours (midnight to midnight).

Monthly mean discharge is the arithmetic mean of the daily mean discharges over a calendar month.

Annual mean discharge is the arithmetic mean of the daily mean discharges over a water year (1 Jan. to 31 Dec.).

The daily mean discharges have been obtained by combining the data from the recorder near the State Highway Bridge with stage discharge or rating curves and tables prepared by the Ministry of Works Hydrological Survey.

5.2 Gaugings:

Appendix A contains details of most of the known gaugings of the Waimakariri River. The first set, taken in 1866 by James Crawford for the provincial engineer, is given for historical interest only, as there is considerable doubt whether a discharge of 1,530,000 gallons per minute or 4090 cusecs, could represent a low flow at the gorge bridge.

The following sets of gaugings have been taken.

Table 3: WAIMAKARIRI RIVER GAUGINGS

Authority	*Number*	*Period*
Canterbury Provincial Council	7	Feb./Mar. 1866
Christchurch City Council	4	1899 — 1907
„ (C. B. Hawley and Co. Inc.)	11	Feb./May 1923
„ (Municipal Electricity Dept.)	76	1923 — 1939
Waimakariri River Trust	39	1928 — 1947
Ministry of Works (Christchurch Hydrological Survey)	155	1950 — 1970
North Canterbury Catchment Board	88	1953 — 1970

Table 4: FLOW DATA SHEET 1967

WAIMAKARIRI RIVER No. 664000 AT WRIGHT'S CUT 3M70

MAP REFERENCE S76/009700 CATCHMENT AREA 1240 Sq. MILES

The discharges given on this sheet are subject to errors caused by variations in cross sections of the river at the recorder site – see Appendix B.

DAILY MEAN DISCHARGES – CUSECS.

	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1	2400	4991	1300	2150	5575	2350	1650	3525	6722	2500	3101	12650
2	2400	2050	1691	2281	5063	2200	1600	3388	8206	2400	3038	9950
3	2400	1912	2616	2300	4525	2050	7400	5063	6138	2544	3288	8600
4	2350	1825	2741	2100	4075	1950	12050	7446	5063	11095	3413	7772
5	2300	1551	2841	1900	3725	1800	6350	5550	4600	6200	3225	21114
6	2689	1450	2711	1775	3413	1700	4450	4025	4150	4300	3116	11400
7	3828	1413	6229	1744	3163	1650	3600	3413	4000	4000	16049	8850
8	2444	2032	2788	10781	3413	1600	3225	3038	3675	4300	12919	7600
9	2400	3069	2600	17066	3988	1600	2913	2725	3225	4450	8700	6850
10	2400	2033	6541	11575	5362	1563	2613	2600	3225	4150	6750	6350
11	2350	1488	22920	7063	4750	1563	2450	15337	3350	3600	6013	5800
12	2250	1450	30405	5413	4375	1525	2350	16661	3163	3288	5750	5100
13	2350	1450	9433	4338	3600	1413	2200	16094	2975	3350	5838	4700
14	2450	1450	5976	3825	3163	1338	2050	9225	2913	3475	5269	9998
15	2400	1413	3513	3475	3100	1300	1950	7850	2788	3350	10328	18513
16	2350	5651	1806	3163	3038	1300	1850	6975	2663	3413	17581	9625
17	2250	8531	1488	2913	2725	1300	1750	5663	2550	3413	25456	7100
18	2200	2988	1563	2726	2550	1300	1700	4988	2675	3100	19809	5925
19	2200	1750	1525	2500	2450	1300	1850	4525	3163	2975	15294	5200
20	2200	1525	1488	2350	2300	1300	1900	4075	3475	6790	12119	4700
21	2250	1413	1488	2250	2150	1413	1700	3788	3413	7513	10600	4300
22	2356	1338	1488	2200	2050	1682	1600	3600	3288	5075	10100	4100
23	4152	1300	1507	5634	1950	1450	1525	3538	3100	4600	9950	4200
24	2850	1300	1600	10263	1981	1300	1450	4400	2913	4150	19360	4400
25	13617	1300	2670	5808	3622	1588	1375	4600	2850	3725	19117	4925
26	11136	1300	5880	13022	3288	2250	1300	4225	2788	3475	13791	4700
27	4100	1300	3432	31741	3413	2000	1300	4000	2613	3288	12932	3900
28	2438	1300	2432	10838	3475	1750	1338	3863	2613	3100	40342	4025
29	1900	–	2037	7675	3163	1650	1338	3600	2788	2913	20006	4300
30	1575	–	2100	6300	2788	1650	1300	3600	2725	2913	17038	3900
31	2069	–	2150	–	2500	–	1263	3850	–	2913	–	3550
Totals	97054	60573	138959	187169	104733	48835	81390	175230	107810	126358	360292	224097
Monthly Mean Discharges	3131	2163	4483	6239	3378	1628	2625	5653	3594	4076	12010	7229

Annual mean discharge 4,692 cusecs

Max. peak discharge 72,400 cusecs on 11/12 MARCH

Min. discharge 1,225 cusecs on 31 JULY

Table 5: FLOW DATA SHEET 1968

WAIMAKARIRI RIVER No. 664000 AT WRIGHT'S CUT 3M70

MAP REFERENCE S76/009700 CATCHMENT AREA 1240 Sq. MILES

The discharges given on this sheet are subject to errors caused by variations in cross sections of the river at the recorder site – see Appendix B.

DAILY MEAN DISCHARGES – CUSECS

	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1	3250	1875	6659	1800	2450	3475	4200	2875	2800	2450	11550	8844
2	3509	1875	2975	5065	2450	3100	3500	2800	2400	4616	9850	6125
3	3983	2807	2250	4100	3660	2875	2800	2725	2250	15581	8725	5100
4	4400	13325	2000	2350	3800	2725	2400	2525	2150	13238	8225	4900
5	3550	5363	1850	2050	5481	2525	2250	3050	2100	15852	7975	5200
6	5475	3500	1800	1875	4800	2400	2150	4275	2475	11425	7475	5794
7	4050	2738	1825	1825	9647	2525	2050	3250	2450	8100	6650	15496
8	3250	3597	2063	1775	5950	3063	2050	2875	2575	6600	6047	11425
9	2950	5877	11045	1831	3850	3550	2100	2800	10225	9831	21293	7913
10	2725	15825	10750	16044	3175	3100	2100	2650	7000	8875	10000	6250
11	2575	7750	6897	10696	2725	2650	2150	2594	4300	6975	7475	5000
12	2450	4600	7381	7913	2450	2450	2350	7550	3400	5600	6525	4450
13	2350	3900	5700	7470	2300	2350	2300	12319	3025	4900	6200	4300
14	2500	3575	6369	6188	2150	2300	2100	10225	3025	4700	6000	4750
15	2350	3025	5950	5750	2203	2200	2050	6775	2950	4375	5900	4675
16	2250	2800	4700	5540	6731	2100	2025	5300	2725	4350	7250	4075
17	2150	2650	3825	4850	3813	2100	3044	4400	2575	4200	7600	3850
18	6285	2400	3400	4000	7088	2100	2600	3650	2400	3800	7725	3625
19	7850	2250	3100	3700	4700	2100	2300	3325	2250	4300	7506	3550
20	4325	2150	2875	3700	6394	2050	2150	3100	2200	4600	6800	3625
21	3175	2050	2800	3900	10962	1950	2050	2800	2150	4200	5500	3250
22	2600	1950	2500	3900	6150	1900	2325	2650	2200	4100	6966	3000
23	2300	1900	2150	3625	4125	1900	9713	2650	6964	13612	5800	3050
24	2150	1900	2100	3475	3325	1900	10300	2575	5000	14813	4775	2600
25	2100	1850	2000	3400	2950	1900	7850	2575	3375	7625	7644	2150
26	2100	1825	1900	3325	9016	1875	5650	2575	5378	8102	10319	1963
27	2100	1850	1875	3100	8700	1850	4200	2400	5750	23635	11100	2163
28	2100	1825	1850	2800	5700	1850	3475	2200	3875	22875	6950	2400
29	2075	3725	1825	2575	5200	3788	3025	2100	3025	13831	5600	2275
30	2250	–	1800	2500	4400	6281	2800	2225	2650	26723	5650	2113
31	2050	–	1800	–	3900	–	2875	3397	–	15200	–	2000
Totals	97227	110757	116014	131122	150245	76932	102932	117210	105642	299084	237075	145911
Monthly Mean Discharges	3136	3819	3742	4371	4847	2564	3320	3781	3521	9648	7903	4707

Annual mean discharge 4,618 cusecs
Max. peak discharge 36,500 cusecs on 23 OCTOBER
Min. discharge 1,750 cusecs on 8 APRIL

It should be recorded that the Ministry of Works over the last twenty years has made available to catchment boards a wide range of gauging equipment which has permitted gaugings at much higher discharges than formerly. Better gauging techniques have become possible through the use of modern equipment not available in the river trust era.

5.3 Design discharge and floods:

Up to 1958 the critical factor in the minds of the river authorities was the determination of design discharge. Gaugings were taken at as wide a range of flow as possible at the Highway Bridge and the Gorge Bridge. The technical difficulties

THE WAIMAKARIRI RIVER AS A WATER RESOURCE

Table 6: FLOW DATA SHEET 1969

WAIMAKARIRI RIVER No. 664000 AT WRIGHT'S CUT 3M70

MAP REFERENCE S76/009700 CATCHMENT AREA 1240 Sq. MILES

The discharges given on this sheet are subject to errors caused by variations in cross sections of the river at the recorder site – see Appendix B.

DAILY MEAN DISCHARGES – CUSECS

	JAN	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1	1850	1627	7994	1400	1700	1675	1661	1300	1500	2600	2300	1725
2	1738	1672	3288	1375	1757	1625	1713	1474	1475	2500	2125	1725
3	1738	1450	2238	1350	1713	1575	1600	1853	1425	2400	1975	1725
4	1775	1350	1926	1363	1998	1525	1575	1575	1425	2250	1900	1675
5	1813	1300	1775	1475	2363	1500	1550	1475	3472	2163	1863	1819
6	4344	1300	1969	1400	2000	1525	1513	1738	5247	2125	1825	1826
7	2975	1300	3838	1375	1832	1550	5538	2494	7522	2125	1825	1700
8	3438	1288	2151	1363	1841	1525	3625	2038	30697	2125	1863	1675
9	2600	1263	1869	2014	1650	1475	2775	1869	27556	2163	1863	1816
10	2275	1250	1794	1935	1575	1450	2500	3081	15863	2394	1788	3069
11	2188	1250	1738	1688	1550	1425	2249	2759	13775	2175	1863	2188
12	2075	1263	1663	1572	1525	1400	2038	2275	14813	2013	2466	2185
13	1850	1275	1525	9449	1475	1400	1925	2075	11819	1975	2488	2600
14	1775	1275	1475	7722	1450	1375	1775	2000	15274	1938	2650	2138
15	1738	1263	1400	3544	1450	1350	1700	2288	9938	1900	2263	1863
16	1675	1250	1350	2888	1450	2244	1675	2813	9750	1863	2050	1700
17	1625	1250	1611	2338	1425	2494	1650	2500	9550	1863	1975	1913
18	1825	1548	1757	2038	1450	1925	1675	2225	7900	1900	1938	4694
19	1869	2194	1500	1925	1525	1738	1600	2075	6500	1900	1900	5794
20	1738	1563	1425	1832	1500	1813	1525	2000	5500	1863	1900	4125
21	1705	1425	1450	1675	1569	1738	1475	2000	4700	1825	1775	2875
22	1738	1350	2979	1625	3859	1650	1450	1925	4438	2924	1850	2325
23	1675	1325	1988	1959	3228	1575	1425	1775	3950	4253	2663	2163
24	1625	1300	1613	5125	3244	1525	1400	1700	3550	3016	2313	1994
25	1550	1350	1550	2888	2800	1500	1400	1675	3250	3731	1938	6908
26	1475	1400	1550	2288	2325	1500	1463	1625	3363	2700	1788	26944
27	1450	1375	1525	2000	2075	1550	1425	1600	3344	2969	1725	17338
28	1425	1522	1475	1869	2000	1725	1375	1600	3250	5178	1763	8250
29	1425	–	1425	1850	1925	1563	1350	1575	3025	3400	1825	5925
30	1475	–	1400	1775	1850	1550	1350	1525	2825	2775	1788	4600
31	1500	–	1400	–	1775	–	1325	1500	–	2500	–	3700
Totals	59947	38976	62641	73100	59879	48465	57300	60407	236696	77506	60248	130977
Monthly Mean discharges	1934	1392	2021	2437	1932	1616	1848	1949	7890	2500	2008	4225

Annual mean discharge 2,647 cusecs
Max. peak discharge 39,000 cusecs on 8 SEPTEMBER
Min. discharge 1,225 cusecs on 18 FEBRUARY

of gauging high floods at the upper bridge proved too great, but at the Highway Bridge the 1957 flood was gauged near its peak, and this was of considerable value in the design of the Waimakariri River Improvement Scheme 1960.

The North Canterbury Catchment Board, like the Waimakariri River Trust which it succeeded, did not attach great importance to measuring low flows until 1967, when the Water and Soil Conservation Act was passed which required regional water boards to investigate all water resources.

5.4 *Flow data 1967-1969*:

The preceding flow data sheets for 1967 to 1969 set out daily, monthly, and annual mean discharges for the river at Wright's Cut, 3M70. The notes by the

Board's design engineer, Mr G. D. Stephen, included in Appendix B, explain how the flow data were compiled and the effects of shingle removal and natural alterations in the river. The flow data are only approximations because of changes in the channel and in mean bed level at the recorder site, but they are the best available figures and of considerable help in the present examination. Refer to Tables 4, 5 and 6 for flow data from 1967 to 1969.

5.5 Flow data 1928-1934:

A summary of monthly mean discharges at White's Bridge or the Highway Bridge for the period 1928 to 1934 was discovered recently, but there is no trace of the daily records or of the calculations, which are thought to have been destroyed by fire on 27 July 1935.

Table 7. MONTHLY, ANNUAL, & LONG-TERM WAIMAKARIRI RIVER DISCHARGE SUMMARIES (FLOWS IN CUSECS AT HIGHWAY BRIDGE)

	YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	MEAN
Waimakariri River Trust	1928	2860	1810	1970	4800	6280	3420	3080	2790	5380	8300	7000	5450	4451
	1929	6000	2890	4400	2250	2370	5220	5750	5520	6620	6880	9050	11300	5709
	1930	12040	5296	3997	3326	3077	3033	2658	3406	5096	6219	7497	5697	5115
	1931	9993	4815	2510	5566	2294	3987	3225	3185	3445	6053	4460	4817	4543
	1932	3810	3564	2200	3120	3432	1818	1635	1810	3020	5730	4430	3300	3168
	1933	1720	7180	2729	5500	5300	1950	3260	3830	2250	3360	3050	4800	3727
	1934	5200	1950	1950	4040	4650	3430	3025	4375	3980	7350	2560	1704	3696
N.C.C.B.	1967	3131	2163	4483	6239	3378	1628	2625	5653	3594	4076	12010	7229	4692
	1968	3136	3819	3742	4371	4847	2564	3320	3781	3521	9648	7903	4707	4618
	1969	1934	1392	2021	2437	1932	1616	1848	1949	7890	2500	2008	4225	2647
Origin	Minimum	1720	1392	1950	2250	1932	1616	1635	1810	2250	2500	2008	1704	1897
	Average	4982	3488	3000	4165	3756	2867	3043	3630	4480	6012	5997	5323	4229
	Maximum	12040	7180	4483	6239	6280	5220	5750	5653	7890	9648	12010	11300	7808

Table 7 shows this new information along with that for 1967-69. The agreement between the two sets of data is fair, considering the known limitations and the short periods involved of seven years and three years. The average of these annual mean discharges for the 10 years is 4236 cusecs, and the average for the last three years is 3986 cusecs. The annual mean discharge for 1969 is only two thirds of this, or 2647 cusecs.

5.6 Flow duration curves:

Flow duration curves at Wright's Cut for the water years 1967, 1968 and 1969, together with the average curve for these three years, are given in Figure 4. The curve for 1969 shows that a flow of 1330 cusecs was exceeded at Wright's Cut for 96% of the year. Figure 5 shows the flow duration curves for the two six month periods from 1 October 1967 to 31 March 1968 and from 1 October 1968 to 31 March 1969.

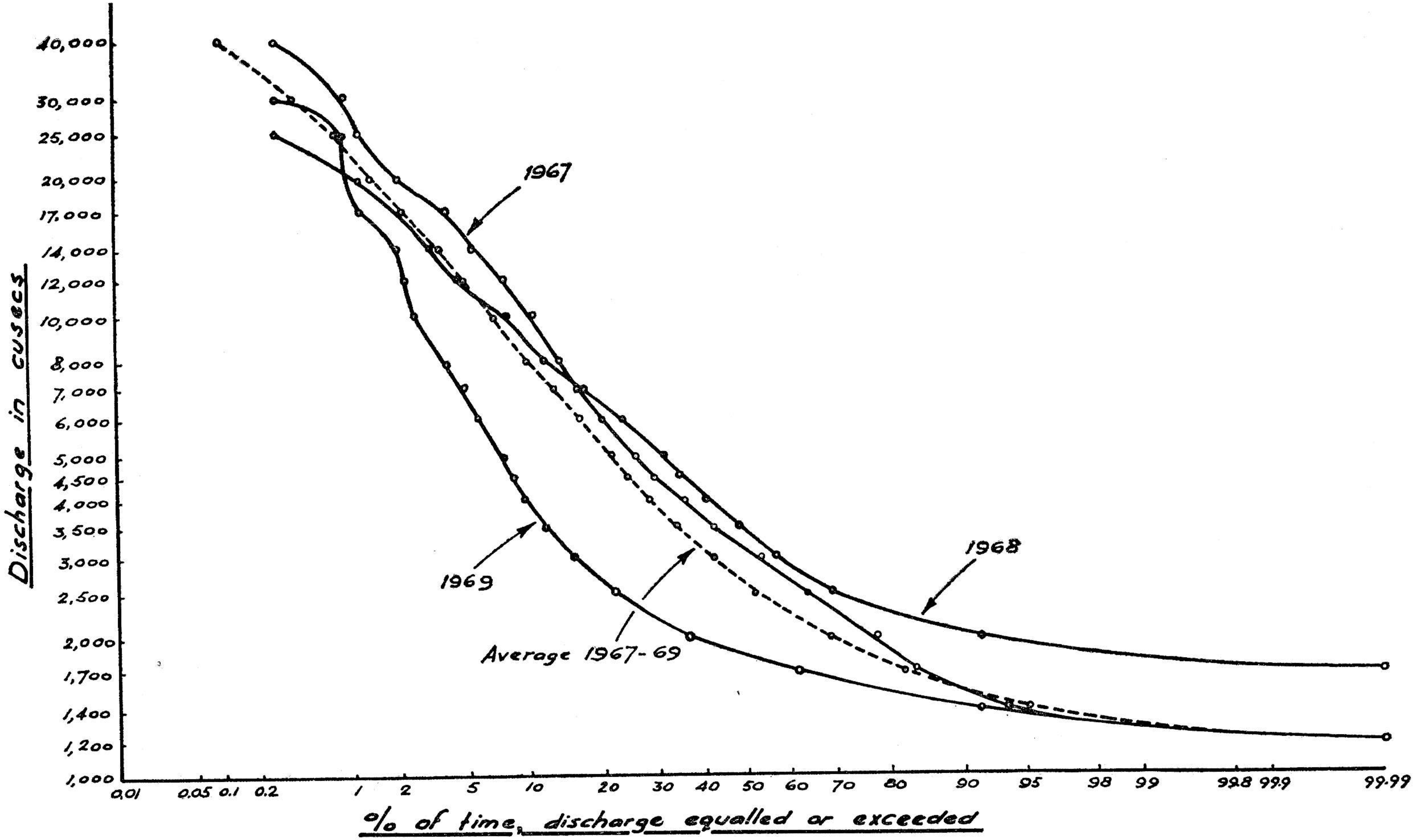

Figure 4: FLOW DURATION CURVES AT WRIGHT'S CUT (3M70)

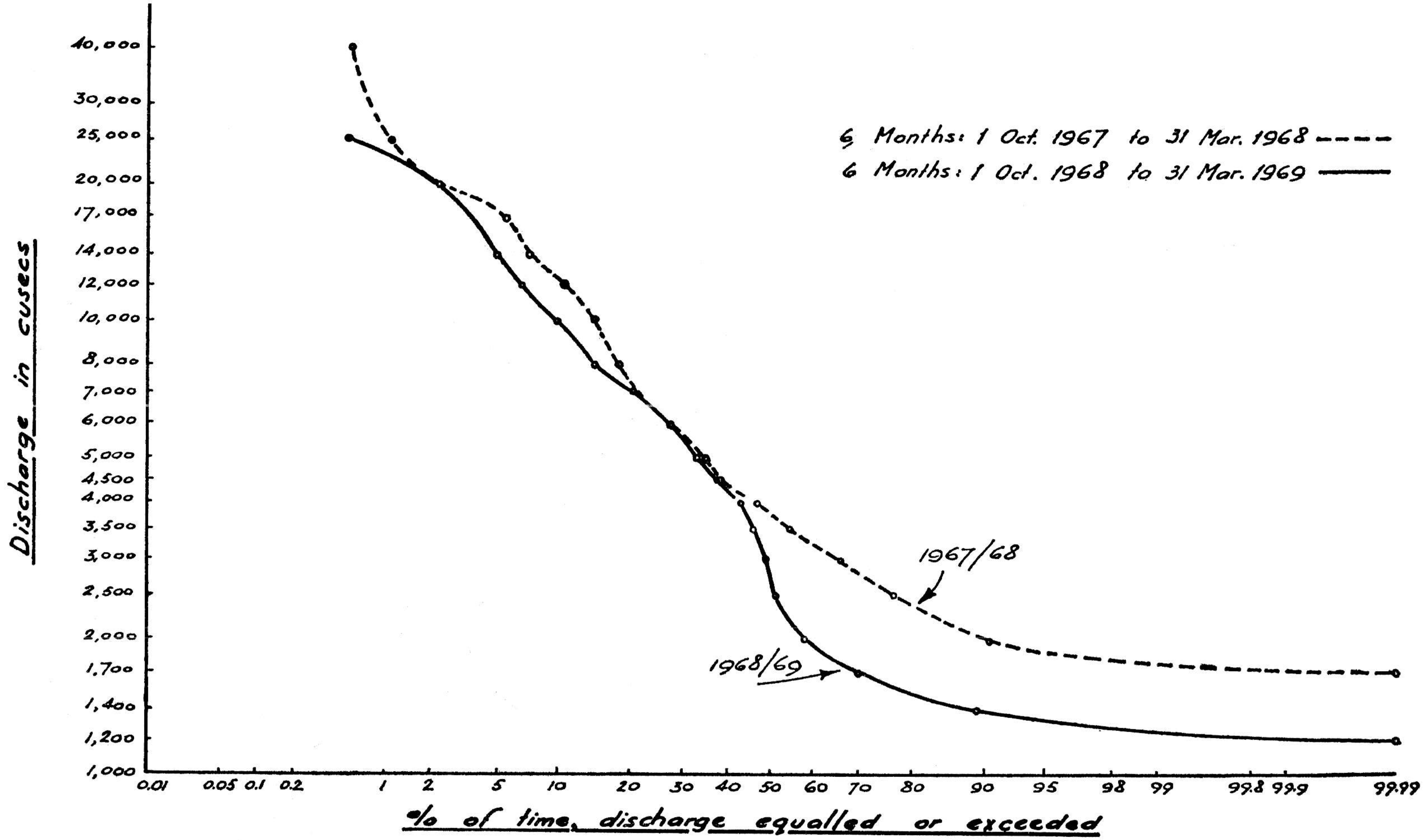

Figure 5: FLOW DURATION CURVES AT WRIGHT'S CUT (3M70)

6. LOW FLOWS

The low flow is a limiting factor upon every use of a river. A summary of all the low flows that have been gauged below certain discharges is set out in Table 8. The limiting values were chosen to make allowance for tributaries between gauging stations. At low flows the Gorge Bridge results are usually at least 100 cusecs more than those at Otarama, and a similar position applies at the Highway Bridge compared with Wright's Cut.

Table 8: LOW FLOW GAUGINGS OF WAIMAKARIRI RIVER

OTARAMA UNDER 1500 CUSECS		*GORGE BRIDGE UNDER 1700 CUSECS*		*WRIGHT'S CUT UNDER 1500 CUSECS*		*HIGHWAY BRIDGE UNDER 1600 CUSECS*	
28-4-23	1410	24-6-Jul-07	1690	18-1-56	1286	17-3-50	1361
2-5-23	1300	13-2-57	1586	7-4-59	1320	22-3-53	1420
4-8-23	1356	6-4-59	1667	23-2-64	1420	1-3-56	1383
16-3-28	1321	6-5-60	1462	30-6-64	1474	9-5-60	1225
22-4-30	1355	2-4-62	1510	7-4-65	1440	13-5-60	1478
6-5-30	1212	5-2-63	1670	20-6-67	1290	4-1-61	1401
13-5-30	1118	20-2-70	1610	20-6-67	1320		
24-6-30	1219	20-2-70	1630	20-2-70	1323		
9-7-30	951	27-2-70	1560	22-4-70	1400		
16-7-30	968	22-4-70	1686	27-5-70	1350		
12-7-33	1418	8-5-70	1620	3-6-70	1330		
2-3-34	1395	26-5-70	1500				
4-5-39	1372	26-5-70	1460				
26-5-70	1320						

It should not be thought that Table 8 includes anything like the number of times the river has been low within these years, because the river authorities used to concentrate upon gaugings during freshes and floods. The Municipal Electricity Department of the Christchurch City Council was, on the other hand, primarily interested in low discharges, and their low flow gaugings are therefore of particular value in this study.

The lowest flows that have been gauged are

Otarama	951	cusecs	on	9/7/30	and	968	on	16/7/30.
Gorge Bridge	1460	„	„	26/5/70	„	1462	„	6/5/60.
Wright's Cut	1286	„	„	18/1/56	„	1290	„	20/6/67.
Highway Bridge	1225	„	„	9/5/60	„	1361	„	17/3/50.

The Otarama gaugings correspond to discharges at the Gorge Bridge of between 1050 and 1100 cusecs, and so are relatively much lower than all the others.

7. INFILTRATION

Infiltration is the passage of water into the soil surface.

7.1 Doyne's Underground Stream:

There has always been considerable interest in the apparent loss of water by infiltration into the bed of the Waimakariri River. Doyne (1865) states in his second report upon the Waimakariri River: 'Great bodies of water are seen to

leave the channel of the Waimakariri on the south side near the point A [Halkett EBD] during freshes; they disappear under the surface, and have no outlet anywhere on the plains.

'The evidences which I have collected leave no room for doubt that there is a great permanent underground stream leaving the present Waimakariri at and for miles below the point marked A --------, and returning to it over miles in length in the neighbourhood of "B" [near the present airport EBD].

'In this fact has consisted the safety of Christchurch in the past, and on it alone depends its safety for the future.'

At least one of Doyne's prophesies was correct, that large quantities of water disappear under the surface in the neighbourhood of Halkett, although it has taken over a century to ascertain the facts and to establish the extent of this infiltration.

7.2 Speight's Report:

Professor R. Speight held the chair of geology at Canterbury University College, and was a member of the Waimakariri River Trust from 1930 to 1938. On 4 July 1927 he made a report to the Trust on the Waimakariri basin (published in 1928), in which he refers at p. 219 to seepage and underground percolation from the river Waimakariri supplying well defined underground streams, which find their way towards Lake Ellesmere and Christchurch 'contributing in no small measure to the supply of water obtained from the artesian wells of that area and also to the springs and small streams which rise where the normal underground flow is checked by the admixture of impervious clay beds with the gravels of the plains. This accounts for the rivers Halswell, Heathcote, Avon, and Styx. The artesian wells are known to respond to high levels of water in the Waimakariri, thus indicating that they owe a portion at least of their water to this source.---- It is therefore probable that there is a diminution of the volume of the river in its middle course; that is, from Courtenay to the top of Coutts' Island ----. However, comparisons of the flow of the river at the Gorge Bridge with those made at White's Bridge show little or no falling off in volume. A set of comparative records of flow at the two places obtained by the Trust's engineers are as follows:

Gorge Bridge	White's Bridge
1700 cusecs	1650 cusecs
4500 „	4200 „
10500 „	10200 „
41000 „	40700 „

'This shows a very slight falling off, and a portion of it is no doubt due to the 25 or 30 cusecs or so which are taken away in distributory water races. Of course the nature of the bed of the river and the conditions of the stream militate against very accurate observations, and the difference is well within the possibilities of error, still there does appear to be a little falling off.'

7.3 Vindication:

Between 1950 and 1964 a number of gaugings by both the Board and the Ministry of Works showed that there were significant differences in flow at the Gorge Bridge and the Highway Bridge, but the full facts were finally established when the Ministry of Works, at the request of the Board, carried out a comprehensive series of gaugings on one day, 5 February 1970, at specific gauging stations

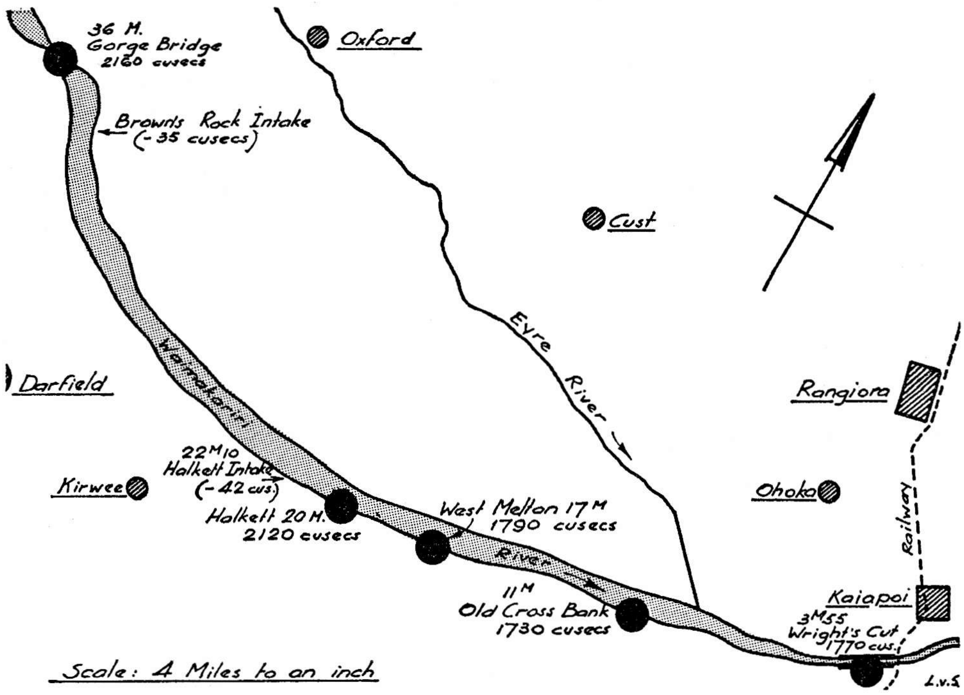

Figure 6: GAUGINGS ON 5 FEBRUARY 1970

on the river. The facts have thus at long last been determined, and Speight's views have been shown to be correct. It is of interest that the final answer to the questions raised by Doyne and Speight could not be given until simultaneous gaugings, and difficult gaugings, became possible with the use of jet boats.
These gaugings are illustrated in Figure 6, and detailed in Table 9.

Table 9: WAIMAKARIRI RIVER FLOWS 5 FEBRUARY 1970

Gauging Site	*Mileage*	*Flow (cusecs)*	*Time of gauging*
Gorge Bridge	36M	2160	1025 — 1105
Halkett Groyne	20M	2120	1200 — 1235
West Melton Groyne	17M	1790	1345 — 1420
Old Cross Bank	11M20	1730	1030 — 1650
Wright's Cut	3M55	1770	1450 — 1530

7.4 Comparative Gaugings:

Comparative gaugings showing the reduction in flow between the Gorge Bridge and Wright's Cut or the Highway Bridge are set out in Table 10. The difference in flow between Wright's Cut and the Highway Bridge is due to the discharge out of the South Branch, and the average flow into the main river has been taken as 130 cusecs. The only known gaugings of the South Branch are set out in Table 11.

Table 10: COMPARATIVE GAUGINGS AT GORGE BRIDGE, WRIGHT'S CUT, AND HIGHWAY BRIDGE

GORGE BRIDGE $36^{M}00$				WRIGHT'S CUT				HIGHWAY BRIDGE $3^{M}20$			
DATE	GAUGING No.	GAUGE M.S.L.	DISCHARGE cusecs	DATE	GAUGING No.	GAUGE at H.W. Bridge M.S.L.	DISCHARGE cusecs	DATE	GAUGING No.	GAUGE M.S.L.	DISCHARGE cusecs
14-3-50	SI 47	10.7	1803					17-3-50	SI 49	NA	1361
23-3-53	NC 3	11.1	1873					22-3-53	SI 360	6.59	1420.
5-5-55	SI 705	14.34	24579					5-5-55	NC 42	9.95	22169
17-1-56	NC 50	12.02	1788	18-1-56	NC 51	NA	1286				
29-2-56	SI 774	12.09	1971					1-3-56	SI 775	6.29	1383
13-1-59	NC 102	11.7	2635					13-1-59	NC 103	6.45	2044
6-4-59	NC 107	11.4	1762	7-4-59	NC 108	5.98	1320				
12-1-60	SI 1141	11.0	2210					12-1-60	SI 1142	6.62	1824
6-5-60	NC 131	10.63	1462					9-5-60	NC 132	5.74	1225
4-1-61	NC 145	11.06	1886					4-1-61	NC 146	6.3	1401
18-12-61	NC 167	10.55	2299					18-12-61	SI 1263	6.11	1853
13-2-64	NC 205	11.60	2088	14-2-64	SI 1678	NA	1580				
5 -2 -70	SI 5722	11.26	2160	5 -2 -70	SI 5718	3.60	1770				
20-2-70	SI 5751	10.91	1610	20-2-70	NC 267	3.18	1323				
22-4-70	NC 272	11.10	1686	22-4-70	NC 273	3.10	1400				
26-5-70	SI 6022	10.92	1500	27-5-70	SI 6025	3.33	1350				
26-5-70	SI 6023	10.91	1460								

NOTES.
1. Abstractions for stock water and irrigation below Gorge Bridge range between 112 and 136 cusecs.
2. The South Branch enters the river at 3m50, ten chains upstream of the Motorway Bridge.
3. Highway Bridge gaugings include the discharge from the South Branch, which was gauged on 27-6-56 at White's Bridge at 162 cusecs, and on 23-9-70 at 150 cusecs.

SI – South Island Hydrological Survey, now Christchurch Hydrological Survey.
NC – North Canterbury Catchment Board.

Table 11: SOUTH BRANCH GAUGINGS

No.	*Date*	*Gauge ht. ft. MSL*	*Flow in cusecs*	*Location*
SI 820	16 Apr. 1956	N.A.	98	Above Dickey's Road
NC 63	27 June 1956	11.63	132	At Dickey's Road
NC 64	,,	9.97	162	White's Bridge
SI 1032	20 Nov. 1958	N.A.	95	Above Dickey's Road
NC 133	9 May 1960	10.47	119	Dickey's Road
SI 1256	6 Dec. 1961	N.A.	118	,, ,,
NC 260	11 Nov. 1969	9.00	85	,, ,,
NC 292	23 Sept. 1970	9.40	134	,, ,,
NC 293	,,	N.A.	150	Near outlet

SI—South Island Hydrological Survey, now Christchurch Hydrological Survey.
NC—North Canterbury Catchment Board.

7.5 *Otarama and Gorge Bridge:*

Table 12 gives recent comparative gaugings by the Christchurch Hydrological Survey showing increases in flow due to added water from the Kowai River and smaller tributaries.

Table 12: COMPARATIVE GAUGINGS OTARAMA AND GORGE BRIDGE

Date	*Otarama flow in cusecs*	*Gorge Bridge flow in cusecs*
12 March 1970	2550	2650
8 May 1970	1550	1620
26 May 1970	1320	1500
,, ,, ,,		1460
5 June 1970	4520	4960
30 June 1970	1770	1860
21 July 1970	4660	5820

8. EXISTING ABSTRACTIONS

(a) Malvern County Council, Kimberley water race. This is taken at the Gorge Bridge from the right bank through a tunnel under the bridge at 36M00.	35 cusecs
(b) Waimakariri Ashley Water Supply Board. A major water race system for stock watering is supplied from the Brown's Rock intake on left bank at 33M55.	35 cusecs
(c) Malvern County Council for the Darfield water supply by pumping out of the bed of the river at 30M04, Bleak House, at rate of 1 cusec.	
(d) Paparua County Council for stock water supply, from the right bank at Halkett Intake, 22M10.	42 cusecs
(e) Dixon's irrigation intakes on the left bank at 11M40 and 12M25. Water is taken intermittently.	24 cusecs

An application has just been made to take 70 cusecs from the river on the left bank at Downs Road 18M26 for irrigating four properties.

9. RIVER CLASSIFICATION

The present water classification of the lower Waimakariri River and its tributaries, gazetted on 15/3/67, is shown on plan No. M311, p. 54. The sea coast from Woodend beach south for seven miles is in class SB, and the estuary up to the mouth of the Kaiapoi River is class SC. A small stretch of water in the South Branch at a picnic spot called the 'Groynes' about a mile west of Belfast is to bathing standard class C. All other waters within the area defined on the map are in the lowest classification for fresh water, class D (basic quality).

Class C is intended for recreational use including swimming.
Class D allows waters to be used for recreation, fishing, (but not swimming), agricultural use, and general industrial water supplies.
Class SC refers to saline waters in estuaries used for recreation and fishing, and
Class SD is intended for open coastal areas used for the same purposes, but not for bathing.

No industrial wastes enter the river above the outlet of the South Branch at 3M50, and Lorimas Road 6M00 is the point up to which shingle contractors operate regularly in removing shingle from the channel proper. There would seem no reason why the river west or upstream of Lorimas Road should not be reclassified in the highest available water quality classification.

10. THE USERS

The report up to this stage has recorded the known physical facts about the Waimakariri River, with particular reference to gaugings and discharge. Brief reference was made to the rainfall records and to the influence of snow. Present takings from the river have been listed and the classification of the lower reaches by the Pollution Advisory Council in 1967 has been described. It has been shown that low flows at Otarama do not reach 1000 cusecs, but have been measured at the Gorge Bridge at 1460, and at 1286 cusecs in Wright's Cut. The annual mean

discharge at the Highway Bridge last year was 2647 cusecs, or less than half the figure of 5709 cusecs obtained 40 years before. It is now proposed to consider the use being made of the river.

10.1 Who uses the water?

The present use made of the water in this river will be outlined before discussing any potential or future uses. It is not always easy to distinguish between users and uses, so the following list contains aspects of both. The list is not in any order of priority.

(a) Those using underground water fed from the river,
(b) Recreational users — bathers, jet-boaters, water skiers, campers, fishermen, picnickers, yachtsmen, power boaters,
(c) Fish,
(d) Birds and other wild life,
(e) Water-race systems supplying stock water in adjoining counties,
(f) Shipping interests,
(g) Domestic water supplies,
(h) Fire-fighting,
(i) Contractors, for casual or intermittent uses,
(j) Irrigation,
(k) Dilution of trade wastes or sewage or animal wastes,
(l) Transport of solid wastes,
(m) Source of shingle for industry,
(n) Watering stock grazing the berms,
(o) Many storm water outlets in the borough of Kaiapoi.

To these must be added the primary function of the river as a drainage channel for discharges ranging from 1000 to 150,000 cusecs in the lower reaches and for smaller discharges in the upper catchment. Included in this function is the transportation of large quantities of debris, silt, and shingle from the total catchment of 1415 sq. miles. The functions of the river as a drainage channel for flood water from innumerable watercourses, and to provide local drainage, must remain unimpaired.

Some of these uses are commented upon below.

10.2 Underground water users:

It is shown in Table 13 that between the Gorge Bridge and Wright's Cut, or between the Gorge Bridge and the Highway Bridge, flow reductions average 382 cusecs at normal discharges of the river. These reductions or apparent losses of water have been assessed after allowing for any additions or abstractions of water between the gauging stations. Such reductions can only occur from infiltration, transpiration or evaporation, alone or in combination, and they are much too large to be accounted for by instrumental error or imperfect measurement. One other set of gaugings is not recorded in Table 13, this being during a small flood on 5 May 1955 when 24579 cusecs was measured at the Gorge Bridge and only 22169 cusecs at the Highway Bridge. The reduction of 2540 cusecs or 10.3% could be accounted for in part by storage within the bed while the river was in violent change. The reductions shown in the table were measured during normal flows when the river was in a steady state and neither rising nor falling.

It is not thought that transpiration or evaporation would be material factors in

Table 13: REDUCTIONS IN FLOW DOWNSTREAM OF GORGE BRIDGE (cusecs)

	A	B	C	D1		D2		E*	%
Date	*Flow added by* Gorge Bridge	South Branch	*Taken for stock etc.*	*Flow through Wright's Cut* date	cusecs	*Flow past Highway Bridge* date	cusecs	*Reduc-tion* cusecs	*100 x E / A*
14-3-50	1803	130	100			17-3-50	1361	472	26.2
23-3-53	1873	130	100			22-3-53	1420	483	25.8
17-1-56	1788		100	18-1-56	1286			402	22.5
29-2-56	1971	130	100			1-3-56	1383	618	31.4
13-1-59	2635	130	100				2044	621	23.6
6-4-59	1762		100	7-4-59	1320			342	19.4
12-1-60	2210	130	100				1824	416	18.8
6-5-60	1462	130	100			9-5-60	1225	267	18.3
4-1-61	1886	130	100				1401	515	27.3
18-12-61	2299	130	100				1853	476	20.7
13-2-64	2088		100	14-2-64	1580			408	19.5
5-2-70	2160		100		1770			290	13.4
20-2-70	1610		100		1323			187	11.6
22-4-70	1686		100		1400			186	11.0
26-5-70	1500		100	27-5-70	1350			50	3.3

*(a) These reductions in flow can only come from infiltration, evaporation or transpiration.

(b) Reduction E=A+B−C−D and % reduction=$\frac{E \times 100}{A}$

(c) Average reduction is 382 cusecs or one fifth of the average of these flows at the Gorge Bridge.

a shingle river bed at low flow, compared with the effect of infiltration. Almost the whole reduction in flow on 5 February 1970 over a length of 32 miles of river channel was confined to the three miles between Halkett and West Melton groynes, from 20M to 17M. The difference upstream of 40 cusecs between the Gorge Bridge (36M) and Halkett (20M) is accounted for by abstractions for stock water. The only substantial cause that can be advanced for the apparent loss of 300 cusecs between 20M and 17M is infiltration.

Table 14: AVERAGE REDUCTIONS IN FLOW BELOW GORGE BRIDGE (cusecs)

	Gorge Bridge (4 lowest) 1 to 4	*Reductions downstream*	*Gorge Bridge (next 4 lowest) 5 to 8*	*Reductions downstream*	*Gorge Bridge (next 4 lowest) 9 to 12*	*Reductions downstream*
	1462	267	1762	342	1886	515
	1500	50	1788	402	1971	618
	1610	187	1803	472	2088	408
	1686	186	1873	483	2160	290
Totals	6258	690	7226	1699	8105	1831
Averages	1564	172	1806	425	2026	458

Another point that shows up from analysis of the results in Table 13 is that the reductions are lowest at extreme low flows. From Table 14 it can be seen that the average reduction for the four smallest discharges is 172 cusecs, but that for the next four lowest it is 425 cusecs. One would expect differences to vary with

total flow, but the variation from 172 to 425 cusecs with a small increase in gross flow is extraordinary. The difference is still surprising even if the figure of 50 cusecs on 26 May 1970 is rejected as anomalous.

It would seem that the reductions in flow which occur downstream of the Gorge Bridge are largely from infiltration, that they average nearly 400 cusecs at normal flows, are much lower at extreme low flows, and may be very substantial during floods. Speight suggested that there were well defined underground streams from the Waimakariri which found their way towards Lake Ellesmere and Christchurch, contributing in no small measure to the supply of water obtained from the artesian wells of that area. The old overflow channels radiating out from the right bank of the Waimakariri River in the vicinity of Halkett towards Christchurch and Halswell are shown on a number of maps, and can be readily distinguished on aerial photographs in the Board's possession. It is not generally known that the survey department of the Provincial service strenuously opposed selling the land in these old courses leading to Lake Ellesmere on the ground that they were required as spillways during floods.*

Further consideration of the destinations of water that has escaped underground from the Waimakariri is rather beyond the scope of this report, but the present investigation has opened up a study of compelling interest, and a series of simultaneous river gaugings over a period of some years would provide information of use to geologists. The conclusion at the present time is that the users of artesian water in the area from Christchurch to Lake Ellesmere are users of Waimakariri water to the extent that their supplies are drawn from aquifers fed by infiltration from the Waimakariri River.

10.3 Recreation:

A great deal of use is made of the river by fishermen, jet-boaters, water-skiers, campers and picnickers. There is a limited amount of use for bathing, but this is largely restricted to children playing in shallow streams or pools away from the main stream. The river is very popular with fishermen during the seasons for salmon, trout, and whitebait. A yachting club based at Stewart's Gully has 42 members with 23 boats, and a sailing and power boat club at Kairaki has some 50 members with 20 boats.

Some limited observations made by three members of a jet-boat association on a Sunday afternoon (15 February 1970) gave the following information†:

Table 15: NUMBERS OF PEOPLE USING RIVER BED SUNDAY 15 FEBRUARY 1970

Locality	*Mileage*	*Jet Boats*	*People*	*Remarks*
Gorge Bridge area	Near 36M	9	120	
Pylons to Engelbrecht's	11M to 7M	—	92	
Engelbrecht's to Farrier's	7M to 5M	—	75	
Farrier's to Railway Bridge	5M to 3M20	10	400+	104 cars
Railway Bridge to sea	3M20 to sea	14	N.A.	(too many people to count)

At the Kairaki camping ground 700 campers occupy caravans for six weeks during the Christmas holiday period. The numbers camping each weekend would vary between 100 and 200 for more than half the year.†

* *Lyttelton Times* 6 February 1868.

†Personal communication from (a) Canterbury Branch of the N.Z. Jet Boat Association (Inc.), (b) caretaker.

10.4 Fish and wild life:

A river provides the environment in which fish can breed, feed, mature, and be caught. An inquiry was made of the North Canterbury Acclimatisation Society on the minimum discharge in the river necessary for fish life and for fishing and whether it considered that abstraction of part of the river at low flow would have any deleterious effect upon fish or bird life. The Society's view was that the minimum flow of the river at any time should not fall below the minimum flow in February 1970 plus 25%. It considered that a lower flow than this would have a deleterious effect upon fish and wild life and would result in a much higher level of pollution in the lower part of the system. The least flow gauged in February 1970 at Wright's Cut was 1323 cusecs on 20/2/70, so the Society's recommended limit is 1650 cusecs at Wright's Cut, representing something in excess of 2000 cusecs at the gorge.

The following birds nest in the river bed and are seen frequently in the bed below the gorge bridge: black backed gull, black billed gull, white fronted tern, black fronted tern. It is not known whether these birds would stay in the river bed if the flow were materially reduced.

English experience on river utilization and the preservation of migratory fish life has been dealt with by George Baxter (1961). He states at pp. 241/2 'if the angling by rod and line is to be preserved, more water is required by way of minimum flow, than suffices for the preservation of the fish stocks.- - - -

'Under natural conditions, the angling range of flows varies from river to river and from pool to pool in the same river. So far as it is possible to generalize, the minimum flow required in the smaller rivers is about 25% of the a.d.f. (average daily flow) and in the larger rivers 20%. The maximum in some rivers can be as high as 3 a.d.f. This, however, is exceptional and confined to the "spate" rivers. The more usual maximum is up to about the a.d.f. depending on the degree of turbidity (in some rivers of the peat content) when the flow is approaching flood conditions. Except in pools which are only "fishable" at the higher ranges of flow, these latter levels are, however, unnecessarily high. - - - - Generally, the most suitable levels are in the spring from 25-50% and for the summer angling from 20-35% of the a.d.f. - - - -

'The water needs of migratory fish are smaller than is perhaps generally supposed. - - - - Excepting the freshets, the heights of water required are substantially those represented by the dry-weather flow, subject to the maintenance of a minimum flow of $\frac{1}{8}$ a.d.f. during periods of hot weather.'

Table 16 makes a comparison of catchment data of the Waimakariri River at three points and of the nine largest rivers analysed by Baxter out of the 15 English and Scottish rivers which he examined.

There are significant differences in the flow patterns of the Waimakariri and these other rivers. The application of Baxter's conclusions to New Zealand rivers is discussed in some detail by C. S. Woods (1964), describing fisheries aspects of the Tongariro Power Development Project, pp. 37 to 42. I am not convinced that Baxter's is the right approach in the case of a large mountain torrent.

10.5 Shipping:

The Waimakariri River and its tributary the North Branch, now renamed the Kaiapoi River, are navigable up to the wharf in Kaiapoi, and ships have operated this port for over a century, except for the period from 1936 to 1958. The Kaiapoi Borough Council is the harbour authority, which has harbour assets valued at

Table 16: COMPARISONS OF WAIMAKARIRI RIVER WITH NINE ENGLISH AND SCOTTISH RIVERS (after Baxter)

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
River	*Gauging site*	*Catchment (sq. miles)*	*Average annual rainfall (ins.)*	*Mean flow (cusecs)*	*Mean flow per sq. m. of catchment (cusecs/sq. m.)*	*Minimum recorded flow (cusecs)*	*Min. recorded flow per sq. m. of catchment (cusecs/sq. m.)*	*Peak discharge (cusecs/ sq. m.)*	*Min. recorded flow as % of mean flow*
Waimakariri	Otarama	870	68.7 (1923/31)	4597†	5.3	951	1.09	170	21
,,	Gorge Bridge	950	68.7 (1923/31)	4773*	5.0	1460	1.54		
,,	Wright's Cut	1240	—	4236	3.4	1225	0.99	114	29
Severn		1650	35.5 (1921/36)	2255	1.4		0.12	14	9
Lower Spey		1020	N.A. (1938/45)	2132	2.1		0.37	18	18
Dee		528	45 (1939/49)	1254	2.4		0.33	76	14
Wye		495	53.7 (1937/45)	1203	2.5		0.21	45	9
Garry		149	100 (1935/44)	930	6.2		0.09	68	1
Moriston		151	82.2 (6 years)	739	4.9		0.25	109	5
Shin		191	57.5 (1949/56)	590	3.1		0.09	N.A.	3
Upper Lyon		62	99 (1949/56)	393	6.3		0.10	185	2
Upper Spey		85	N.A. (1936/7)	327	3.9		0.33	72	9

* The mean flow at the Gorge Bridge has been estimated by adding the mean average difference of 537 cusecs between the Gorge Bridge and Wright's Cut to the calculated mean flow at Wright's Cut.

† The mean flow at Otarama has been obtained by deducting a mean average difference of 176 cusecs (based upon an average of five simultaneous gaugings at Otarama and the Gorge Bridge) from the estimated mean flow of 4773 cusecs at the Gorge Bridge.

$139,000, and no indebtedness. One of the points that would have to be examined, in the event of any substantial abstraction of water from the main river, would be the effects upon silting of the channel and upon the bar. All of the harbour area is in tidal water.

11. IRRIGATION

An indication of present thinking on irrigation possibilities within the area between the Waimakariri and Ashley Rivers is given on pages 8 and 9 of Miscellaneous Publication No. 2 issued by the Winchmore Irrigation Research Station, dated April 1970. An article on proposed schemes by P. D. Fitzgerald discusses a Rakaia scheme for 140,000 acres in Ashburton county, and then refers to the following two schemes:

Central Plains Scheme

'This enormous scheme, which covers 259,000 acres, lies between the Rakaia and Waimakariri Rivers from the 750 foot contour to the heavy land near the coast. It is planned to reticulate the area in two sections divided by the Selwyn River. The intake for the South Section is to be about one mile below the Highbank Power Station. It would be necessary for this intake to climb a series of terraces, one of which would provide some difficulty. The main race would have a capacity of 1250 cusecs and extend to the Selwyn River.

'The intake for the North Section is to be at the mouth of the lowest gorge of the Waimakariri River and involves constructing a tunnel 1900 feet long; a 1600 cusec race will cross the river terrace and extend to the Selwyn River. This intake would also supply the Oxford scheme.

'In March 1969 an irrigation demonstration area was set up using water supplied from the Malvern County Council's stock race.

Oxford Scheme

'This 53,000 acre scheme lies on the north bank of the Waimakariri, although considerable areas north of this river could benefit from irrigation, drainage in some cases presents a problem which must be solved before any development is undertaken. The intake would be combined with the intake for the north section of the Central Plains scheme and water conveyed under the Waimakariri River by an inverted syphon 30 chains long.'

12. DILUTION The letters BOD and DO used in this section need some explanation.*

12.1 Industrial wastes:

One of the major services carried out by the Waimakariri River in the lower reach of four miles, from the South Branch to the sea, is the dilution of polluted discharges out of the Kaiapoi River and the South Branch. Industrial waste is carried by these rivers from the following industries.

South Branch:

Zealandia Soap Candle and Trading Co. Ltd., Belfast,
Canterbury Frozen Meat Co. Ltd., Belfast,
Christchurch Drainage Board (temporary oxidation ponds),
Thomas Borthwick and Sons A'Asia Ltd., Belfast.

* BOD and DO: The letters BOD stand for biochemical oxygen demand, and DO for dissolved oxygen; (see Appendix D).

Kaiapoi River and tributaries:
North Canterbury Wool and Fellmongery Ltd., (Kaiapoi River),
Kaiapoi Petone Group Textiles Ltd., (Kaiapoi Mill) (Cam River),
North Canterbury Sheepfarmers' Co-operative Freezing Co. Ltd., (South Branch North Side),
Kaiapoi Borough Council sewerage treatment works (Kaiapoi River),
T. J. Edmonds Ltd. (South Branch, North Side),
Rangiora Borough Council sewerage treatment works (Northbrook),
Peel Products Ltd., Rangiora, (Cam River).

12.2 Condition of river and tributaries:

Three series of tests have been carried out in the lower reaches to assess the condition of four miles of the main stream and more particularly of the two tributaries, the South Branch and the Kaiapoi River. The first of these constituted part of a biological survey by Hirsch (1958) in 1956/7 of organic pollution in a number of New Zealand streams. Some chemical testing was done for Hirsch by the Government Analyst at Christchurch, and the dissolved oxygen data included in his paper are given in Table 18, referred to numbered sampling points in Figure 8.

Table 17: BOD AND DISSOLVED OXYGEN IN WAIMAKARIRI AND TRIBUTARIES (after Christchurch Drainage Board 1963-64)

Site	*BOD (ppm) 12/11/63 to 21/4/64*			*DO (ppm) 28/5/63 to 21/4/64*			*Locality*
	av.	*max.*	*min.*	*av.*	*max.*	*min.*	
1	2.0	5	1	10.6	12.0	9.1	South Branch, Dickey's Road
2	14.4	23	5	9.0	10.4	7.5	South Branch, near outlet
3	0.9	1	0.5	11.5	12.6	9.3	Waimakariri, Wright's Cut
4	2.4	4	1	11.0	12.5	9.0	Waimakariri, Stewart's Gully
5	4.2	8	1	8.5	10.4	5.6	Kaiapoi River, below Kaiapoi
6	2.1	4	1	10.5	12.0	8.8	Waimakariri River, Kairaki

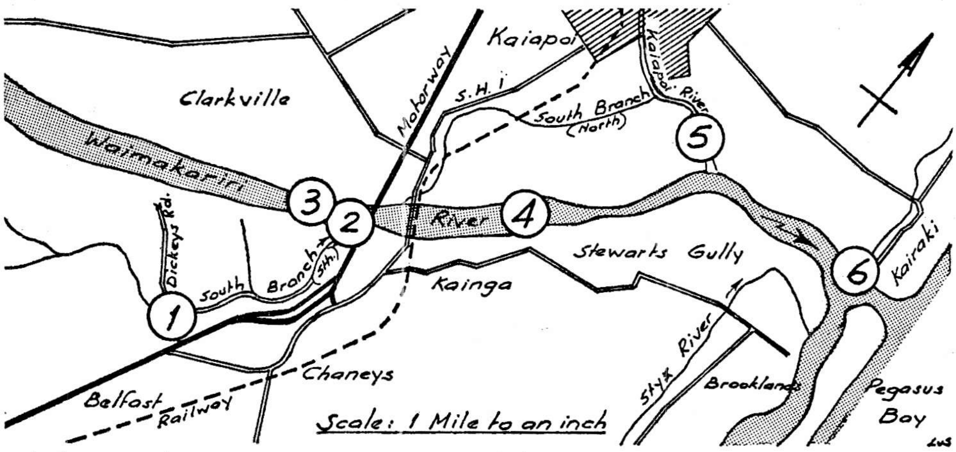

Figure 7: SAMPLING POINTS CHRISTCHURCH DRAINAGE BOARD TESTS 1963-64

During 1963/64 the Christchurch Drainage Board (1964) carried out a series of chemical and bacteriological tests in these rivers, at three points in the main stream, two in the South Branch, and one in the Kaiapoi River near its junction. The sampling points are shown on Figure 7, and the results, in terms of BOD and dissolved oxygen over the killing season, are given in Table 17. The report upon this testing stated that no evidence was found that the water in the main stream at any point fell below the Pollution Advisory Council's requirements concerning the chemical and physical qualities of class C or class D water (this being before the waters were classified). The pollution load into the South Branch at that time was 13,450 lbs. per day of BOD and 6,500 lbs. per day of suspended solids. The main river at present is class D above the Kaiapoi Junction and class SC downstream, neither of which classes limit the coliform bacteria content. There is doubt whether the lower reaches could meet the bacteriological requirement for class C or class SB waters.

The Christchurch Drainage Board indicated in April 1970 that future domestic and industrial loads could mean that about 50,000 lbs. per day of BOD would require disposal in the Belfast area.

Until recent years general thinking had been that the river was capable of dealing with pollution loads up to about 20,000 lbs. of BOD per day.

Table 18: DISSOLVED OXYGEN IN PPM — WAIMAKARIRI RIVER AND TRIBUTARIES (after Hirsch 1958)

Station	*Dissolved oxygen (ppm)*		*Location*
	June 1956	*Feb. 1957*	
1(S)	10.4	9.9	South Branch below the Groynes
2	10.8	9.1	„ „ above Dickey's Road
5(S)	11.2	7.7	„ „ below Dickey's Road
7	8.2	6.7	„ „ Wilson's Drain
8	8.4	4.9	„ „ White's Bridge near outlet
11	12.5	9.0	Waimakariri at Farrier's, 5M60
12	12.4	4.8	„ below Highway Bridge, 3M
	Aug. 1956	*Feb. 1957*	
1(N)	9.4	9.7	Kaiapoi River (N. Branch) Clothier's Road
3	9.5	8.7	„ „ footbridge below fellmongery
4	9.4	8.1	„ „ bridge, Main Drain Road
5(N)	9.8	8.1	„ „ above railway bridge

The third series of tests was carried out by the Ministry of Works in the Kaiapoi River and its tributaries, together with some sampling in the Styx River and Brooklands Lagoon, between 27 November 1967 and 21 October 1968. The data from these tests have just become available, and within the last week some of the results have been processed and are summarized in Tables 19 and 20. Much more information will be analysed from this Ministry of Works basic pollution survey, which covers other sampling points than those noted in Table 19 and located on Figure 8.

It can be seen from these tables that more information is available about pollution in the lower reaches of the river than had been generally realised. The oxygen

Table 19: POLLUTION SURVEY OF KAIAPOI AND CAM RIVERS BY MINISTRY OF WORKS NOV. 1967 TO OCT. 1968. SAMPLING POINTS SHOWN ON FIGURE 8 (BOD AND DISSOLVED OXYGEN PPM)

site	27 Nov to 13 Dec 1967				18 Jan to 22 Feb 1968				24 Apr to 29 May 1968				22 July to 21 Oct 1968			
	No. of samples	average	maxi-mum	mini-mum	No. of samples	average	maxi-mum	mini-mum	No. of samples	average	maxi-mum	mini-mum	No. of samples	average	maxi-mum	mini-mum
DISSOLVED OXYGEN																
D Kaiapoi River above fellmongery	11	10.2	11.1	8.5	7	9.8	11.8	4.3								
I Kaiapoi River ford below fellmongery	22	9.2	10.8	7.3	13	8.2	10.1	5.1								
L Kaiapoi River near Main Drain Rd.	22	8.1	10.4	4.5	13	6.2	8.9	2.0								
J Kaiapoi River School footbridge	22	9.0	11.5	5.6	14	8.0	11.4	4.7					15	9.9	11.7	7.5
M Cam below Woollen Mills	22	8.3	12.4	4.4	44	7.9	13.3	4.4	42	8.1	11.8	6.0	51	9.6	13.5	5.5
K Cam old course near confluence	22	8.2	11.8	5.5	44	7.8	12.3	4.5	42	7.9	11.1	5.7	51	9.4	12.7	5.8
H Kaiapoi River, main road bridge	22	7.2	9.5	5.0	44	6.7	9.2	4.5	41	7.5	9.4	6.2	51	9.1	11.1	6.9
F Kaiapoi River above confluence	11	8.9	10.3	5.2	37	8.3	11.1	5.1	39	9.6	11.7	5.4	19	9.9	12.4	7.6
X Kaiapoi River between floodgates & confluence					30	7.3	9.5	4.8	40	8.4	11.7	6.1	21	9.3	11.5	7.3
BIOCHEMICAL OXYGEN DEMAND																
D Kaiapoi River above fellmongery	8	0.8	1.8	0.0	7	1.4	1.9	1.0								
I Kaiapoi River ford below fellmongery	16	4.9	10.2	1.2	13	6.9	8.6	4.8								
L Kaiapoi River near Main Drain Rd.	16	4.0	6.6	0.0	13	3.7	6.1	1.3								
J Kaiapoi River School footbridge	16	2.2	4.4	0.0	13	2.4	5.2	0.7					5	3.1	4.6	1.1
M Cam below Woollen Mills	16	5.8	9.6	1.0	31	6.7	12.3	0.7	34	6.1	10.4	1.3	29	5.9	10.0	1.7
K Cam old course near confluence	16	4.2	9.7	1.2	31	5.4	11.6	0.4	34	4.4	9.0	0.7	29	4.0	8.6	0.9
H Kaiapoi River, main road bridge	16	2.6	4.3	0.9	31	3.1	6.4	0.8	34	3.1	6.0	0.8	29	2.9	8.6	0.0
F Kaiapoi River above confluence	8	2.2	4.7	0.3	23	2.0	5.6	0.3	32	2.3	5.9	0.9	5	3.0	4.2	1.7
X Kaiapoi River between floodgates & confluence					18	2.6	6.4	0.4	33	3.4	7.0	0.5	5	3.3	3.9	2.5

content of the main river appears to be still satisfactory, but this aspect is under study. It has been shown that there is considerable pollution in the South Branch and in parts of the Kaiapoi River. The Pollution Advisory Council pointed out in circular G7 of 31 July 1969 that some of the existing outfalls contribute to extensive bacteriological pollution at Brooklands Lagoon and Waimakariri River mouth. Table 20 gives the results of tests at Brooklands Lagoon.

Table 20: POLLUTION SURVEY BY MINISTRY OF WORKS AT BROOKLANDS LAGOON, AT POINT C ON FIGURE 8

date	dissolved oxygen (mg/l)	temperature (°C)	oxygen deficiency (mg/l)	BOD (mg/l)	pH <7 acid >7 basic	total alkalinity (mg/l $CaCO_3$)	total hardness (mg/l $CaCO_3$)	chloride (mg/l)
28/11/67	9.4	16.2	0.5	1.7	6.5	30	45	110.0
29/11/67	9.8	19.4	−0.6	1.3	6.4	27	21	40.5
30/11/67	7.9	15.9	2.0	1.8	6.5	46	36	63.5
1/12/67	8.9	18.2	0.6	0.3	5.4	38	47	158.0
4/12/67	9.0	16.3	0.3	1.1	7.6	55	162	<250
6/12/67	10.3	11.9	0.5	1.4	7.3	36	177	<250
12/12/67	9.6	20.9	−0.7	NA	7.2	40	202	<250
23/ 1/68	8.4	18.6	1.0	2.0	7.3	56	178	>250
25/ 1/68	9.4	20.7	−0.4	3.0	7.2	58	>250	>250
29/ 1/68	8.4	19.7	0.8	1.8	7.2	60	226	>250
average	9.1	17.8	0.5	1.6	6.9	45	NA	NA
maximum	10.3	20.9	2.0	3.0	7.6	60	>250	>250
minimum	7.9	11.9	−0.7	0.3	5.4	27	21	40.5

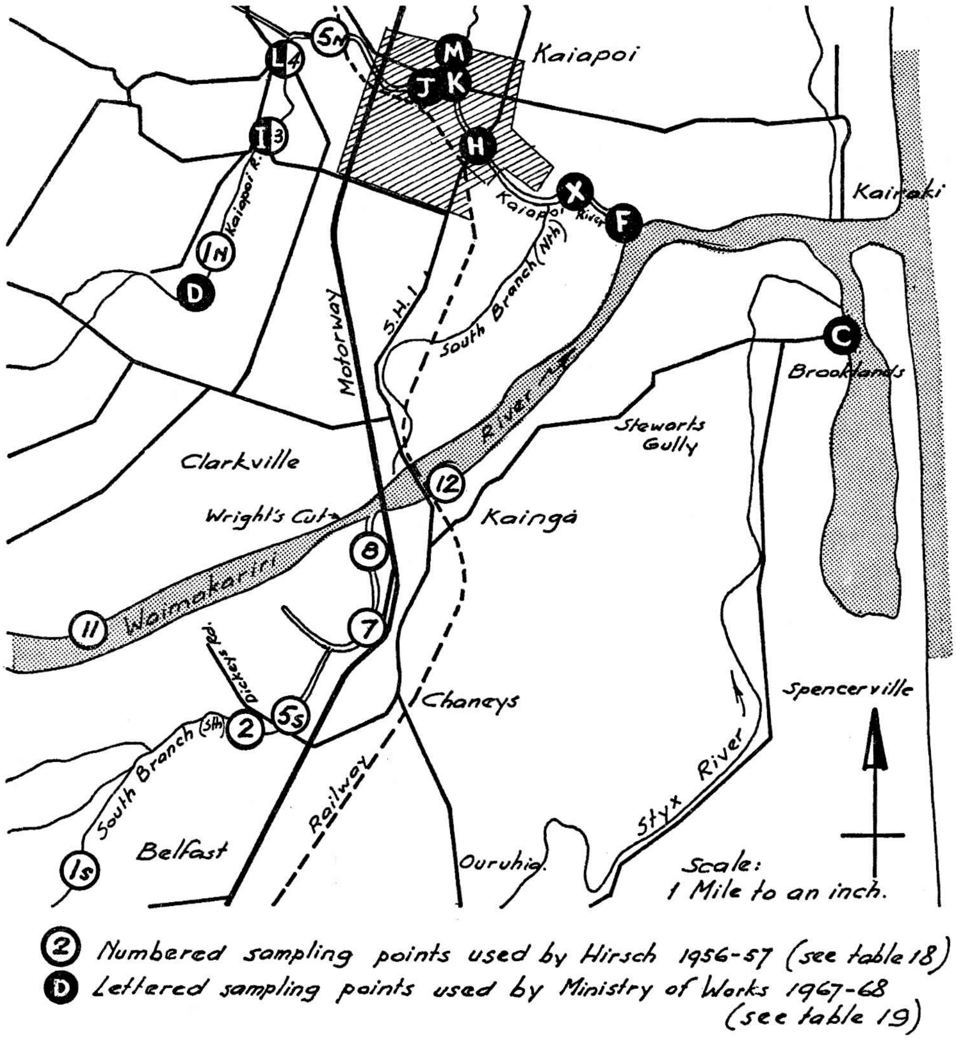

Figure 8: SAMPLING POINTS USED BY HIRSCH AND BY MINISTRY OF WORKS

12.3 The need for treatment:

The Christchurch Drainage Board is at present making a study of the disposal of wastes from the Belfast area and has constructed experimental oxidation ponds near the South Branch. Its comments on dilution were invited, and the present position is that the Christchurch Drainage Board would oppose any reduction in the low flow of the river below 1400 cusecs until the results of an oxygen requirement and resources study were available, and until it was satisfied that its interests would not be affected unduly by any such reduction. It is now clear that a great deal hinges upon the effectiveness of treatment of all industrial wastes before they enter the Waimakariri River or its tributaries.

13. CONSIDERATIONS

13.1 Statutory rights:

Under the Water and Soil Conservation Act 1967 the sole right to take natural water is vested in the Crown, with certain exceptions. The City of Christchurch Electric Power and Loan Empowering Act 1902 permitted the city to take water from the Waimakariri River to produce energy. It is not known whether this Act has been repealed. The taking had to be at least 40 chains above the Gorge Bridge. The bed of the river below the Gorge Bridge is vested in the Board. The Waimakariri-Ashley Water-supply Board, and the Malvern and Paparua County Councils, have certain statutory water-race rights which have to be preserved.

13.2 Infiltration:

The dependence, if any, of other areas upon water derived from infiltration is a matter that requires investigation. The question that has to be answered is 'Is this infiltration really necessary?'

13.3 Economic factors:

No attempt has been made in this report to examine economic aspects, though it is apparent that at least some of the industries discharging into the river could not carry on without some means of waste disposal. The dilution at present available in the river and its two lower tributaries is a vital factor in the operation of three freezing works and a number of other industries. Any major change in waste disposal from these industries would take time and large capital sums.

13.4 The suggested limitations:

The North Canterbury Acclimatisation Society has suggested that the minimum allowable flow in Wright's Cut should be 1650 cusecs, and the Christchurch Drainage Board has mentioned the figure of 1400 cusecs. The allowable abstractions just upstream of Wright's Cut have been examined in the light of the flow duration curve for the six month period October 1968 to March 1969, and the results are set out in Table 21. It does not follow that similar abstractions made at the Gorge Bridge would have the same consequences.

Table 21: TABLE SHOWING PERCENTAGES OF TIME AND NUMBER OF DAYS CORRESPONDING TO QUANTITIES OF WATER ABSTRACTED IMMEDIATELY UPSTREAM OF WRIGHT'S CUT ASSUMING (a) 1400 CUSECS AND (b) 1650 CUSECS RETAINED IN THE RIVER

Abstracted	*If 1400 cusecs retained*		*If 1650 cusecs retained*	
(cusecs)	*% of time (182 days)*	*No. of days*	*% of time (182 days)*	*No. of days*
0 — 100	89 — 81	162 — 147	72 — 68	131 — 124
100 — 200	81 — 75	147 — 137	68 — 63	124 — 115
200 — 300	75 — 70	137 — 127	63 — 59	115 — 107
300 — 400	70 — 65	127 — 118	59 — 57	107 — 104
400 — 500	65 — 61	118 — 111	57 — 55	104 — 100
500 — 600	61 — 58	111 — 106	55 — 53	100 — 96
600 — 700	58 — 56	106 — 102	53 — 52	96 — 95
700 — 800	56 — 54	102 — 98	52 — 51	95 — 93
800 — 900	54 — 53	98 — 96	51 — 50	93 — 91
900 — 1000	53 — 52	96 — 95	50	91

13.5 Applications for water rights:

Any Minister may apply to the Minister of Public Works for the right to take water, and such applications are to be referred to regional water boards for consideration and recommendations. All other applications for the taking of water, for purposes other than domestic, stock, and fire-fighting, have to be made to the Board, and must go through formal processes of advertisement, objection, consideration, decision. The Board's part in the procedure is both investigatory and judicial, and so it is not able to make any decision concerning the availability of water in advance of an application for water, made in compliance with regulations that have been laid down. It would therefore be improper for this report to include recommendations for the allocation of water for any future use, and any comments made can only relate to present use and demands upon the river.

14. CONCLUSION

For nearly a century the Waimakariri River has been looked upon as a potential source of water, and this report indicates the size of that resource. There have been proposals to supply the city with gravity water supply from the river, and this would have been done had underground water not been available. It may be that the Waimakariri is the primary source of the underground water, a point to be resolved by the geologists.

The use limitations imposed by the river itself are those of flooding and low flow. During floods it is not possible to take water for any purpose. It would be expensive to store it. Floods control the means of taking water, while the low flows control the amount that may be taken. The paramount issue is the effect that any abstractions would have upon infiltration at Halkett.

The uses made of the Waimakariri River are outlined in the report. One of these has been the dilution of industrial waste. If there are proposals for change, cost-benefit analyses of competing demands will have to be made by some competent authority. No reduction in the low flow can be contemplated while dilution is so important, but there are also other factors to consider. It would be a pity to spoil the Waimakariri River in the course of civilising it.

15. ACKNOWLEDGEMENTS

I gratefully acknowledge the assistance given me by my staff in the preparation of this report. I especially thank G. D. Stephen, who was responsible for Tables 4, 5, 6 and 21, and for Appendix B; L. A. A. van Schooten for Figures 1 to 8 and for redrawing the water classification map; and D. N. Duffield for compiling most of Appendix A. Special reference is also made to the assistance so willingly given by the Ministry of Works in river gauging, water testing, and the preparation of rating tables. I thank the Department of Lands and Survey, New Zealand, for permission to use map copyright material in the preparation of all the maps.

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APPENDIX A

JOURNAL OF PROCEEDINGS OF THE CANTERBURY PROVINCIAL COUNCIL SESSION XXVI 1866 p. 149

WAIMAKARIRI RIVER

First Gaugings of the Waimakariri River (taken under the direction of E. Dobson, Provincial Engineer, by James Crawford, and reported to the Provincial Government on 22 October 1866).

		Velocity in feet per minute						
Date when River Gauged	*Location*	*Surface of Water*	*Bottom of Water*	*Mean Velocity*	*Area of discharge **	*Discharge in Gals. per Min.*	*Remarks*	*Flow in cusecs †*
21st Feb. 1866	Gorge	274.40	246.40	260.40	243.161	1.514.908	While gauging this part of the river was low	4053
23rd Feb. 1866	Breakwater	302	260	281	248.326	1.546.058	,, ,, ,,	4139
24th Feb. 1866	Forks	296.40	256.40	276.40	245.231	1.527.789	,, ,, ,,	4087
7th March 1866	Kaiapoi							
,, ,, ,,	South branch	292	274	283	66.071	411.622		1101
,, ,, ,,	North branch	439	419	429	361.073	2.249.474	While gauging this part there was a considerable fresh in river	6018
16th March 1866	North branch	330	294	312	227.258	1.415.817	Second gauging	3788
,, ,, ,,	South branch	276	252	264	51.405	320.153	,, ,,	857

(Notes by E.B.D. * Area of discharge is a mistake. The figures appear to be discharge in cubic feet per minute.
† The column headed flow in cusecs has been added for comparison.)

Comment by the Provincial Engineer:

"From the gorge to the forks above Kaiapoi Island, the average discharge when the river is low is at the rate of 1.530.000 gallons per minute, there being apparently no increase in the volume of water as it passes along the shingle plains, but a little above the town of Kaiapoi the volume of water increases to 1.735.000 gallons per minute, of which more than three-fourths now pass through the North Channel.

During the spring freshes the discharge is nearly doubled, and the bed of the river being unable to hold this body of water, the stream overflows its banks at various points from the head of Kaiapoi Island down to the Town of Kaiapoi."

APPENDIX A

GAUGING REFERENCES

Hawley	C. B. Hawley and Coy Inc., for the Christchurch City Council
M.E.D.	Municipal Electricity Department
C.	Christchurch Hydrological Survey
W.R.T.	Waimakariri River Trust
Dobson	Arthur Dobson for the Christchurch City Council
N.C.	North Canterbury Catchment Board

GAUGINGS WAIMAKARIRI RIVER AT OTARAMA, S74:396900

No.		*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
Hawley	1	16-2-23	1029.00	2293
,,	2	1-3-23	1028.90	2264
,,	3	7-3-23	1028.80	1772
,,	4	8-3-23	1028.72	1750
,,	5	14-3-23	1031.80	8701
,,	6	21-3-23	1029.10	2428
,,	7	27-3-23	1029.75	3290
,,	8	12-4-23	1028.70	1858
,,	9	19-4-23	1028.50	1538
,,	10	28-4-23	1028.40	1410
,,	11	2-5-23	N.A.	1300
M.E.D.	1	1-7-23	1029.00	1819
,,	2	4-8-23	1028.60	1356
,,	3	17-8-23	1029.10	2113
,,	4	7-9-23	1029.10	2170
,,	5	12-2-24	1029.90	2843
,,	6	21-3-24	1029.70	2675
,,	7	2-4-24	1028.80	1514
,,	8	16-4-24	1028.80	1611
,,	9	27-4-24	1031.50	5492
,,	10	6-6-24	1029.70	2216
,,	11	27-6-24	1033.50	13560
,,	12	21-8-24	1029.40	2355
,,	13	30-9-24	1030.40	4877
,,	14	22-10-24	1030.20	4913
,,	15	18-11-24	1030.30	5357
,,	16	20-1-25	1028.60	1818
,,	17	6-2-25	1028.60	2039
,,	18	17-6-25	1028.50	2013
,,	19	29-11-25	1030.40	3692
,,	20	26-3-26	1029.30	2099
,,	21	4-4-26	1029.70	2652
,,	22	14-4-26	1029.60	2229
,,	23	14-7-26	1029.30	2397

No.		*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
M.E.D.	24	18-7-26	1029.60	2739
,,	25	19-8-26	1029.20	2195
,,	26	8-9-26	1028.70	1758
,,	27	8-12-26	1033.30	13966
,,	28	6-3-27	1028.70	1645
,,	29	21-5-27	1029.40	3349
,,	30	5-6-27	1029.20	2999
,,	31	4-8-27	1028.30	2134
,,	32	10-8-27	1028.30	2011
,,	33	3-9-27	1028.60	2648
,,	34	12-1-28	1028.10	2330
,,	35	26-1-28	1027.80	1819
,,	36	2-2-28	1027.70	1609
,,	37	14-2-28	1027.80	1674
,,	38	16-3-28	1027.50	1321
,,	39	22-11-28	1029.70	3929
,,	40	1-3-29	1028.70	1559
,,	41	24-4-29	1028.80	1658
,,	42	15-8-29	1028.75	1888
,,	43	29-9-29	1029.30	2727
,,	44	28-12-29	1031.50	6265
,,	45	14-3-30	1028.60	1902
,,	46	22-4-30	1028.20	1355
,,	47	6-5-30	1028.10	1212
,,	48	13-5-30	1028.00	1118
,,	49	24-6-30	1028.10	1219
,,	50	9-7-30	1027.90	951
,,	51	16-7-30	1027.90	968
,,	52	12-12-30	1029.60	2812
,,	53	25-4-31	1030.20	2121
,,	54	16-5-31	1029.50	1518
,,	55	8-1-32	1030.50	2790
,,	56	2-3-32	1030.20	2630
,,	57	14-4-32	1030.60	2458
,,	58	21-6-32	1029.90	1720
,,	59	27-6-32	1030.20	2466
,,	60	14-7-32	1029.70	1605
,,	61	13-9-32	1030.20	2232
,,	62	22-11-32	1030.10	2492
,,	63	8-12-32	1030.30	2045
,,	64	5-1-33	1029.80	2446
,,	65	30-3-33	1029.90	1813
,,	66	23-6-33	1029.50	1586
,,	67	12-7-33	1029.50	1418
,,	68	6-9-33	1029.70	2012
,,	69	2-3-34	1029.30	1395

No.	*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
M.E.D. 70	13-4-34	1029.30	1876
„ 71	14-6-34	1029.20	2480
„ 72	26-7-34	1029.20	2190
„ 73	5-10-34	1031.30	5133
„ 74	7-6-35	1030.50	2622
„ 75	10-12-35	1030.50	2987
„ 76	4-5-39	1028.70	1372
C 1275	8-3-62	1030.25	1622
C 1834	17-8-64	1030.92	3065
C 1823	20-8-64	1030.70	2631
C 1857	31-8-64	1030.42	2005
C 1877	14-10-64	1030.98	3201
C 2011	21-1-65	1030.66	2430
C 2026	26-1-65	1031.72	5000
C 2186	6-4-65	1030.15	1650
C 2285	5-7-65	1030.91	2200
C 2314	3-8-65	1030.80	2460
C 2340	31-8-65	1030.68	2690
C 2718	24-6-66	1031.02	2670
C 2773	12-7-66	1030.42	1860
C 2876	21-9-66	1031.55	3570
C 2991	17-10-66	1030.71	2370
C 2992	17-10-66	1030.70	2400
C 3097	23-11-66	1031.25	3200
C 3248	10-1-67	1030.65	2780
C 3429	20-3-67	1031.67	3080
C 3539	19-4-67	1031.22	2600
C 3588	8-5-67	1031.57	4190
C 3589	8-5-67	1031.57	4140
C 3670	26-5-67	1030.86	2940
C 3894	18-8-67	1031.37	3940
C 3925	31-8-67	1031.83	5660
C 3926	31-8-67	1031.94	5800
C 4017	2-10-67	1030.31	2240
C 5259	20-5-69	1030.30	1790
C 5526	13-10-69	1031.25	2150
C 5705	12-1-70	1031.76	2070
C 5702	28-1-70	1032.15	3230
C 5772	17-2-70	1031.12	1610
C 5885	12-3-70	1031.29	2550
C 5980	8-5-70	1030.42	1550
C 6024	26-5-70	1030.25	1320
C 6028	5-6-70	1032.07	4760
C 6029	5-6-70	1032.04	4520
C 6131	30-6-70	1030.60	1770
C 6218	21-7-70	1032.12	4660

GAUGINGS WAIMAKARIRI RIVER AT GORGE BRIDGE, S75:489775

No.	*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
Dobson 1	August 1899		1955
„ 2	17/18 June 1902		2520
„ 3	22/23 Sept. 1903		5580
„ 4	24/26 July 1907		1690
W.R.T. 1	25-1-28	N.A.	1779
„ 2	1-6-29	N.A.	1717
„ 3	8-6-29	815.53	9013
„ 4	6-11-29	818.35	14155
C 47	14-3-50	810.70	1803
C 74	6-9-50	812.40	4526
NC 3	23-3-53	811.10	1873
NC 7	24-6-53	812.70	5338
NC 8	12-10-53	812.55	4700
NC 10	24-12-53	812.05	4745
C 563	2-2-54	816.05	28849
NC 17	29-4-54	811.10	1805
NC 19	26-5-54	811.30	1804
NC 20	16-6-54	814.05	11956
NC 30	29-9-54	811.70	3674
NC 31	13-10-54	814.00	10521
NC 32	13-10-54	813.85	10780
NC 34	17-2-55	814.60	16757
NC 35	18-2-55	814.70	14580
NC 38	13-4-55	811.12	1973
C 705	5-5-55	814.34	24579
NC 50	17-1-56	812.02	1788
C 774	29-2-56	812.09	1971
C 956	12-5-56	812.30	2219
NC 74	13-11-56	816.60	20079
NC 75	13-2-57	811.90	1586
NC 87	3-1-58	813.40	11378
NC 99	26-9-58	811.90	2255
NC 100	23-10-58	812.55	3892
NC 102	13-1-59	811.70	2635
NC 106	6-4-59	811.40	1667
NC 107	6-4-59	811.40	1762
NC 114	14-6-59	817.20	39139
NC 125	28-8-59	811.60	2082
NC 126	16-9-59	815.96	23341
NC 127	2-10-59	813.80	12151
NC 128	30-10-59	812.15	4067
C 1141	12-1-60	811.00	2210
NC 130	17-3-60	811.70	3828

No.	*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
NC 131	6-5-60	810.63	1462
NC 135	22-5-60	815.45	19012
NC 136	22-5-60	815.86	21932
NC 141	26-8-60	810.80	2336
NC 142	9-9-60	814.85	17151
NC 143	28-10-60	810.92	2728
NC 145	4-1-61	811.06	1886
NC 167	18-12-61	810.55	2299
C 1270	7-2-62	810.41	1978
C 1276	16-3-62	810.36	1731
NC 175	2-4-62	810.10	1510
NC 186	18-12-62	810.62	2170
NC 190	5-2-63	810.30	1670
NC 205	13-2-64	811.60	2088
NC 226	31-7-67	811.18	1911
C 5699	15-1-70	812.09	3550
C 5701	15-1-70	812.04	3550
C 5722	5-2-70	811.26	2160
C 5751	20-2-70	810.91	1610
C 5752	20-2-70	810.90	1630
C 5776	27-2-70	810.85	1560
C 5886	12-3-70	811.47	2650
NC 272	22-4-70	811.10	1686
C 5979	8-5-70	811.03	1620
C 6022	26-5-70	810.92	1500
C 6023	26-5-70	810.91	1460
C 6032	5-6-70	812.65	4960
C 6130	30-6-70	811.42	1860
C 6220	21-7-70	813.10	5820

*GAUGINGS WAIMAKARIRI RIVER AT WRIGHT'S CUT, S76:009700

No.	*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
NC 51	18-1-56	—	1286
NC 108	7-4-59	5.98	1320
NC 168	21-12-61	5.95	1578
C 1523	15-7-63	7.01	10600
NC 200	17-12-63	4.01	1830
C 1677	12-2-64	6.14 W.C.	1740
C 1678	14-2-64	—	1580
C 1702	23-2-64	—	1420
C 1739	15-4-64	7.90 W.C.	1810

No.	*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
C 1764	15-5-64	7.00	11640
C 1775	30-6-64	7.54 W.C.	1474
C 1860	14-8-64	5.70	5447
C 1835	18-8-64	8.94 W.C.	3023
C 1881	15-10-64	8.90 W.C.	2948
C 2022	22-1-65	9.98 W.C.	4560
C 2024	25-1-65	6.00	8710
C 2027	27-1-65	5.21	4079
C 2060	11-2-65	8.31 W.C.	2130
C 2146	19-3-65	7.53 W.C.	1810
C 2187	7-4-65	7.75 W.C.	1440
C 2218	30-4-65	4.70	2570
C 2259	26-5-65	5.23	4500
C 2286	6-7-65	7.50 W.C.	2130
C 2316	4-8-65	3.99	2280
C 2342	1-9-65	3.73	2440
C 2392	5-10-65	6.43	12900
C 2395	6-10-65	5.47	7740
C 2396	7-10-65	4.94	6050
C 2399	8-10-65	4.48	4830
C 2775	13-7-66	3.08	1650
C 2875	21-9-66	7.81 W.C.	3800
C 3000	20-10-66	7.19 W.C.	2230
C 3098	23-11-66	3.15	3670
C 3185	13-12-66	7.77 W.C.	4130
C 3186	13-12-66	8.05 W.C.	4450
C 3187	13-12-66	8.58 W.C.	5890
C 3188	13-12-66	8.62 W.C.	5590
C 3254	13-1-67	3.05	2080
C 3255	13-1-67	3.00	2220
C 3279	23-1-67	8.08 W.C.	6470
C 3280	23-1-67	8.76 W.C.	6130
C 3281	23-1-67	8.55 W.C.	6060
C 3669	25-5-67	3.65	3920
C 3713	20-6-67	2.36	1290
C 3714	20-6-67	4.00	1320
C 4303	19-1-68	—	6860
C 4346	30-1-68	3.90	2490
C 4420	25-3-68	3.75	1760
C 4421	26-3-68	3.72	1710
C 4422	26-3-68	3.72	1700
C 4670	1-7-68	4.65	4370
C 4671	1-7-68	4.60	4390
C 4780	12-9-68	4.30	3630
C 4831	24-10-68	6.84	14200
C 4832	24-10-68	6.50	11800

No.	*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
C 4958	20-1-69	3.70	2550
C 5388	29-8-69	3.65	1510
C 5443	12-9-69	6.84	15000
C 5531	30-10-69	4.25	2640
C 5559	25-11-69	3.86	1820
C 5661	19-12-69	5.30	6040
C 5718	5-2-70	3.60	1770
NC 267	20-2-70	3.18	1323
NC 273	22-4-70	3.10	1400
C 5982	4-5-70	4.05	1570
C 6025	27-5-70	3.33	1350
C 6031	3-6-70	3.25	1330
C 6219	20-7-70	3.35	1770
C 6293	3-9-70	7.00	12400
C 6302	3-9-70	6.83	11860
C 6303	4-9-70	6.38	9580
C 6304	4-9-70	6.33	9470
C 6305	4-9-70	6.28	9340
C 6295	7-9-70	6.90	13280
C 6294	7-9-70	6.87	12700

* The above gaugings were all taken above the confluence of the South Branch.
'W.C.' after the gauge height refers to a staff gauge in Wright's Cut, now washed away. All other gauge heights were measured at the Highway Bridge recorder.

GAUGINGS WAIMAKARIRI RIVER AT HIGHWAY BRIDGE, S76:018705 (INCLUDING 5 AT MOTORWAY BRIDGE, S76:015703)

No.	*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
W.R.T. 5	19-12-31	3.65	5000
„ 6	24-12-31	5.60	13100
„ 7	12-4-32	4.53	7930
„ 8	25-6-32	3.25	1900
„ 9	11-10-32	5.60	12800
„ 10	1-2-33	9.30	30850
„ 11	15-2-33	10.10	35000
„ 12	15-7-33	8.60	27200
„ 13	11-8-33	6.30	11350
„ 14	21-9-33	5.50	7875
„ 15	18-12-33	5.90	11550
„ 16	10-1-34	3.65	4000
„ 17	24-1-34	3.40	3230
„ 18	26-1-34	7.70	21750

No.	*Date*	*Gauge Height ft. M.S.L.*	*Flow in cusecs*
W.R.T. 19	12-4-34	3.60	2625
„ 20	11-5-34	3.40	3365
„ 21	16-5-34	6.70	14500
„ 22	19-5-34	4.50	5435
„ 23	28-6-34	6.50	14250
„ 24	28-6-34	6.00	10900
„ 25	29-6-34	4.90	6980
„ 26	29-6-34	4.70	6250
„ 27	30-6-34	4.10	4440
„ 28	10-7-34	4.35	4860
„ 29	10-7-34	4.30	4260
„ 30	11-7-34	3.70	3310
„ 31	12-7-34	3.55	3130
„ 32	13-7-34	3.70	3800
„ 33	17-8-34	7.25	17812
„ 34	29-9-34	5.90	10820
„ 35	1-10-34	9.60	28860
„ 36	31-5-35	7.75	21085
„ 37	17-2-36	2.70	2040
„ 38	21-2-36	9.70	28700
„ 39	12-3-47	N.A.	4958
C 49	17-3-50	—	1361
C 82	13-9-50	8.18	7411
C 157	5-2-52	7.28	4780
NC 2	26-1-53	11.90	50675
C 359	22-3-53	—	1615
C 360	22-3-53	6.59	1420
NC 11	7-1-54	9.90	27073
NC 21	17-6-54	12.10	58053
NC 36	19-2-55	13.70	74845
NC 37	26-2-55	11.50	40398
NC 42	5-5-55	9.95	22169
NC 45	27-8-55	11.73	48735
C 775	1-3-56	6.29	1383
NC 61	22-4-56	9.80	25550
NC 84	20-11-57	10.48	25300
NC 85	27-11-57	12.95	52150
NC 86	27-12-57	16.80	111901
NC 88	9-5-58	12.75	50273
NC 103	13-1-59	6.45	2044
C 1142	12-1-60	6.62	1824
NC 132	9-5-60	5.74	1225
C 1159	13-5-60	6.10	1478
NC 146	4-1-61	6.30	1401
C 1263	18-12-61	6.11	1853
NC 169	22-1-62	11.81	33700

No.		Date	Gauge Height ft. M.S.L.	Flow in cusecs
NC 181		10-10-62	8.60	6830
NC 182		25-10-62	8.83	7210
C 1690		17-2-64	—	1640
NC 212		14-5-64	11.73	48900
C 3416	Motorway Br.	11-3-67	12.10	84900
C 3419	,, ,,	11-3-67	10.62	58600
C 3417	,, ,,	12-3-67	8.62	34500
C 3418	,, ,,	12-3-67	10.86	53900
C 3420	,, ,,	12-3-67	9.65	45100
NC 222		12-3-67	8.95	39936
NC 223		27-4-67	10.47	52538
NC 224		27-4-67	10.40	50520
C 3558		27-4-67	10.46	50200
C 3559		27-4-67	10.35	49100
NC 232		28-11-67	10.28	52380
NC 233		28-11-67	10.08	49867
NC 234		28-11-67	9.83	47225
C 4197		28-11-67	9.32	38100
C 4198		28-11-67	9.97	46000
C 4634		14-6-68	3.94	2680
C 4611		20-6-68	3.78	2810
NC 245		23-10-68	9.17	38159
C 4833		25-10-68	5.74	7050
NC 255		8-9-69	9.37	40030
NC 256		8-9-69	9.17	38100
NC 257		9-9-69	8.70	32190
NC 279		29-8-70	9.43	46620
NC 280		29-8-70	9.27	43730
NC 281		29-8-70	8.79	38180
NC 282		29-8-70	8.05	29440
NC 283		29-8-70	7.76	26920
NC 284		31-8-70	13.19	86622
NC 285		31-8-70	13.36	85852
NC 289		17-9-70	11.59	71470
NC 290		17-9-70	11.59	63740
NC 291		18-9-70	8.45	28580

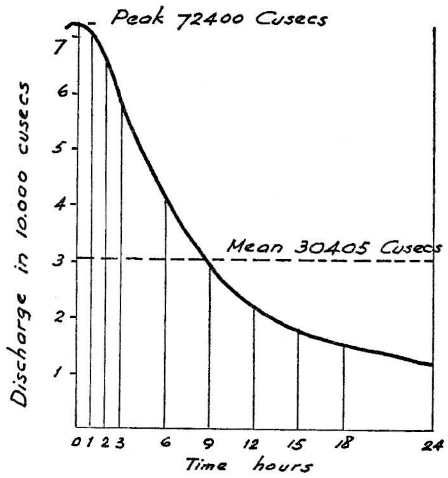
OTHER GAUGINGS

No.	Date	Gauge Height ft. M.S.L.	Flow in cusecs	Site
C 5720	5-2-70	—	1730	11ml. 20ch.
C 5721	5-2-70	—	1790	17ml.
C 5719	5-2-70	—	2120	20ml.

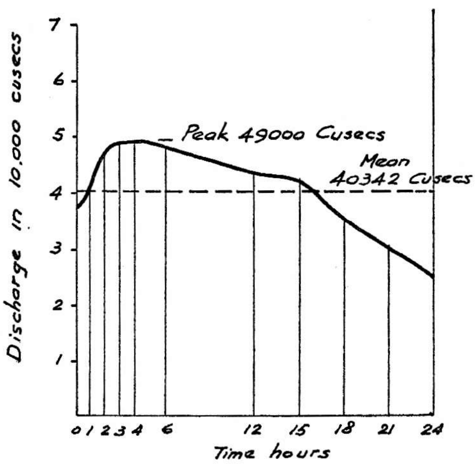
APPENDIX B BY G. D. STEPHEN, DESIGN ENGINEER

CATCHMENT 664000 — WAIMAKARIRI RIVER — WRIGHT'S CUT 3M70
NOTES ON DAILY, MONTHLY AND ANNUAL MEAN DISCHARGES 1967 — 1969

1. The results of the computations of daily, monthly and annual mean discharges in cubic feet per second (cusecs) for the Waimakariri River at Wright's Cut 3M70 for the water years 1967, 1968 and 1969 are given on the flow data sheets, which also show the magnitude and date of the maximum peak discharge for each year. It will be noticed that the date of the maximum *peak* discharge does not necessarily agree with that of the greatest *mean* daily discharge, and in fact the two events can be widely separated in time.
2. The reason for this will be clear from the following two diagrams.



Flow hydrograph 12/3/67
Fig 1



Flow hydrograph 28/11/67
Fig 2

Fig. 1 shows the flow hydrograph of the river for the period 0000 hours to 2400 hours on 12 March 1967. The peak of this flood occurred at midnight on 11/12 March and had a magnitude of 72,400 cusecs. The discharge fell quite rapidly and the mean discharge for the following 24 hours was only 30,405 cusecs. Fig. 2 shows the hydrograph on 28 November of the same year. Here the peak discharge is less than in Fig. 1, but because the flow remained fairly high over the whole 24 hours, the mean discharge is greater than it was on 12 March.
3. For the same reasons given above, the minimum (instantaneous) discharge during the year does not necessarily occur on the same day as the lowest daily mean discharge.
4. The water level recorder installed just upstream of the State Highway Bridge

records continuously the level of the river. To convert this level or stage to discharge requires a rating curve, and this is obtained by carrying out sufficient flow gaugings at different levels to determine a relation between the two. When the river is in high flood, gaugings can only be done from the Highway Bridge, but it has been found convenient to measure the low and medium flows in Wright's Cut about $\frac{1}{2}$ mile upstream.

5. It should be noted that the South Branch joins the Waimakariri River between the Highway Bridge and Wright's Cut. This tributary has a normal flow of the order of 100 cusecs. This discharge would be included in any gaugings taken from the Highway Bridge, but excluded from those taken in Wright's Cut. However, the discharge of the South Branch is quite insignificant compared with flood flows in the main river, and for this reason the daily mean flows etc., given on the flow data sheets can be regarded as applicable to Wright's Cut or a point just upstream of the junction of the South Branch.

6. The plotting of discharges obtained from the flow gaugings in relation to the corresponding river levels, and the derivation of several different rating curves and tables corresponding to different periods from 1967 onwards, has been done by Ministry of Works Hydrological staff. This work has not been easy and has involved considerable judgment regarding the periods over which the field measurements should apply. Any relation between stage and discharge only remains valid so long as the river section *where the water level is recorded* remains stable, i.e. that such parameters as depth and width remain constant. Unfortunately this condition does not hold good at the water level recorder site in question or for that matter at any other site on a river like the Waimakariri. The particular factors that adversely affect the derivation of a reliable stage-discharge relation at the recorder site in question are:

(a) Natural changes in the channel brought about by floods; deposition and removal of bed material.
(b) Changes in the bed caused by the commercial removal of shingle on the north side of the low flow channel opposite the recorder.

Very little can be done about the first of these factors and some gradual aggradation must be expected following the considerable reduction in bed level brought about by the bulk removal of shingle for motorway construction between 1963 and 1967. The reason that no attempt was made to calculate daily mean discharges until 1967 was that the excavation by the Ministry of Works was carried out in such quantities and at such a fast rate that it was considered to be quite impossible to determine a stage-discharge relation that would remain valid over any appreciable period of time. By 1967 it was hoped that conditions had returned to normal, but unfortunately (from the point of view of obtaining reliable flow data in the form now presented) at the end of that year commercial excavation of shingle was commenced along the northern edge of the low flow channel opposite the water level recorder structure, and this has been carried on more or less continuously until the present day. It is difficult to assess the effect of this excavation on the stage-discharge relation in any quantitative manner, or its importance relative to the natural changes, but the formation of new channels by the dragline is most undesirable and could lead to the low flow being diverted away from the water level recorder altogether. If this happens it will be the end of the flow analysis in the form now presented.

7. The actual analysis of the recorder charts, and the conversion of stage to discharge using the rating tables supplied by the Ministry of Works, has been done by Board's staff. So far five different rating tables covering the period from 1 January 1967 to the present date have been used. The periods to which these apply are as follows:

A. 1/1/67 to 27/11/67 (2400 hours).
B. 28/11/67 to 23/10/68.
C. 28/11/67 (0000 hrs.) to 23/10/68 (2400 hrs.).
D. 24/10/68 (0000 hrs.) to 7/9/69 (1500 hrs.).
E. 7/9/69 (1500 hrs.) to present date.

Rating C is a revision of rating B made after a recent review of the gauging data, and by agreement with Ministry of Works staff, ratings A, C, D, and E only have been used in the calculation of daily mean flows for the three years 1967, 1968 and 1969.

8. Some idea of the differences between these ratings can be obtained from the following table which shows the discharges in cusecs corresponding to three different stage heights at the recorder:

	3.0 ft.	*5.0 ft.*	*10.0 ft.*
A.	2400	8950	47000
C.	1300	6100	45000
D.	1125	4300	42500
E.	1300	5200	45000

A stage height of 3 ft. corresponds to low flow, 5 ft. to a small fresh and 10 ft. to a medium flood. While the differences in the discharges at the higher stage are not so pronounced, the differences at both 3 feet and 5 feet, particularly in the case of ratings A and D, are very considerable. The figures also highlight the problem of knowing when to change from one rating to another.

9. Since 1965 the mean bed level of the channel at the recorder site has been determined on several occasions with the following results:

Date	*Mean bed level feet above M.S.L.*
12/1/65	4.65
24/2/67	1.04
4/4/67	1.10
5/4/68	3.82
4/12/69	4.02

These figures are an indication of the lack of channel stability at the site. The low values in 1967 are the result of the massive excavation of shingle by the Ministry of Works for motorway construction. The mean bed levels in 1968 and 1969 both show an increase, and a trend towards the earlier level in 1965.

10. SUMMARY:

Up to the time of the passing of the Water and Soil Conservation Act 1967, the Board's interest in river flow was mainly centred around isolated measurements taken during floods. This information was, and still is, essential for the design of river improvement schemes. The position, however, is now different, and for the determination of water resources the Board needs to know the full range of flows in all the important rivers and streams in its area. Not only are high and low flows required, but also average flows over certain periods. The basis of this sort of information is the determination of daily mean flows in the form presented in the data sheets. Armed with this basic data it is possible to prepare flow duration curves showing the percentage time that any flow is equalled or exceeded. For reasons that have been given it will be evident that the results now presented must be regarded as approximate, and must be treated with caution particularly in the low flow range. It is not very likely that further amendments will be made in the results for 1967 and 1968, but those for the latter part of 1969 could still be subject to alteration when the next rating is established.

APPENDIX C

RAINFALL RECORDS ARTHUR'S PASS 1923—1969

Railway Station site				*Store* (½ *mile nearer pass*)	
year	*ins.*	*year*	*ins.*	*year*	*ins.*
1923	146.29	1941	148.99	1954	154.51
1924	162.81	1942	205.65	1955	178.37
1925	213.66	1943	124.56	1956	180.68
1926	189.86	1944	170.33	1957	230.18
1927	171.29	1945	168.96	1958	219.34
1928	166.39	1946	155.60	1959	168.14
1929	176.71	1947	145.00	1960	181.11
1930	111.78	1948	141.89	1961	166.92
1931	184.84	1949	164.92	1962	173.88
1932	118.75	1950	139.78	1963	156.75
1933	181.09	1951	136.76	1964	198.94
1934	144.80	1952	118.87	1965	173.91
1935	121.70	1953	incomplete	1966	136.85
1936	143.73	1954	,,	1967	246.57
1937	129.12	1955	177.49	1968	207.01
1938	169.95	1956	154.53	1969	163.56
1939	109.02	1957	201.16		
1940	154.89				
Annual averages 1923-52: 153.93 ins.				1954-69: 183.55 ins.	

1. Records taken from daily readings of manual gauges at each site.
2. The 1953 and 1954 railway station records are incomplete, and the 1946 to 1952 figures are not fully confirmed.
3. Incomplete records are held for 1906-7 and 1916-1922. The railway station records ceased May 1958 and the store records commenced August 1953.
4. The results from the two sites are appreciably different.

OTHER RECORDS HELD

1. *Bealey:* 1867-1879; 1890-1936; 1956-1967.
2. *Mt. White:* 1923-1956; broken records thereafter.
3. *Grasmere:* 1930-1949; 1952-1969.
4. *Craigieburn:* 1923-1945; 1955-1958; 1962-1969 incomplete.
5. *Flock Hill:* 1923-1947; 1950-1969 but incomplete.
6. *Mt. Torlesse:* 1909-1920; 1923-1969; 1921/2 incomplete.
7. *Poulter:* 1953-1962 incomplete.
8. *Avalanche Peak:* Feb. 1953-Oct. 1962 not fully processed.
9. *Nigger Hill:* Sept. 1950-1969, with broken periods.
10. *Bull Creek:* Nov. 1962-1969.
11. *Mt. Enys:* Nov. 1960-1969, with broken periods.

APPENDIX D

DEFINITIONS, WITH SOME NOTES ON TERMS USED IN THE REPORT

1. *Aggradation:*

Aggradation is the process of a river depositing some of its waste and so building up its channel to establish or to maintain grade. It occurs when the supply of sediment into a stream exceeds the amount the stream can transport. The term is used in two senses. Aggradation may refer to the actual increase in bed level at a particular river section, or the emphasis may be upon the quantity of material being deposited in a reach of the river.

2. *Biochemical Oxygen Demand (BOD):*

This is the quantity of oxygen in parts per million (ppm) used in the biological and chemical oxidation of organic matter in a stated time and at a constant temperature. The time is generally 5 days and the temperature 20° Centigrade. It is often thought that the BOD test is a chemical reaction, but it is not; it is essentially bacterial (refer Hynes, The Biology of Polluted Water, p. 60). Note that parts per million (ppm) and milligrams per litre (mg/l) mean the same thing.

There are many references to BOD values in Tables 17 to 20. These should be read in the light of the findings of the Royal Commission on Sewage Disposal (1898 to 1915) which considered that the dissolved oxygen absorption test gave an indication of the cleanliness of a river. The BOD test can be looked on as a purely arbitrary measure of the oxygen taken up by a sample of river water during a period of 5 days at 20° C., and thus as an arbitrary measure of the amount of putrescible material in the water (Hynes: p. 4 and p. 59). River waters were classified by the Royal Commission as follows:

Condition	*BOD (parts per million dissolved oxygen absorbed in five days)*
Very clean	1
Clean	2
Fairly clean	3
Doubtful	5
Bad	10

The Commission recommended that a BOD of 4 parts per million should not be exceeded in the receiving river water. When waste flows into a river the ratio of the discharge of the river to that of the effluent is known as the dilution factor. If a river flow of 8 cusecs has a BOD value of 2, and the waste discharge has a BOD value of 20 at a discharge rate of 1 cusec, the resulting flow downstream would be 9 cusecs with a BOD value of 4.

3. *Discharge or Flow:*

The quantity of water flowing past a given section in unit time, (which could be 1 second, 1 hour, or 1 day).

4. *Dissolved Oxygen (DO):*

This is the oxygen present in solution in water but not chemically combined with the water. The solubility of oxygen in water varies inversely with the temperature, and it is not so much the actual amount of dissolved oxygen which matters as the percentage saturation. At normal atmospheric pressure 100% saturation value varies from about 14 parts per million (ppm) at 0^0 C., to zero at the boiling point of water (Hynes, p. 21). The average saturation level at normal temperatures is in the vicinity of 10 ppm.

5. *Flow duration curve:*

A graph showing the percentage of time that any flow is equalled or exceeded.

6. *pH Value:*

The pH value (hydrogen ion concentration) indicates the degree of acidity or alkalinity of a liquid. A pH value of 7 represents a neutral condition. Values from 7 to the maximum of 14 represent alkaline condition, and values below 7 acid condition. pH4 is more acid than 6, and pH10 is more alkaline than 8, the variation away from 7 giving a measure of the acidity or alkalinity.

7. *Simultaneous gaugings:*

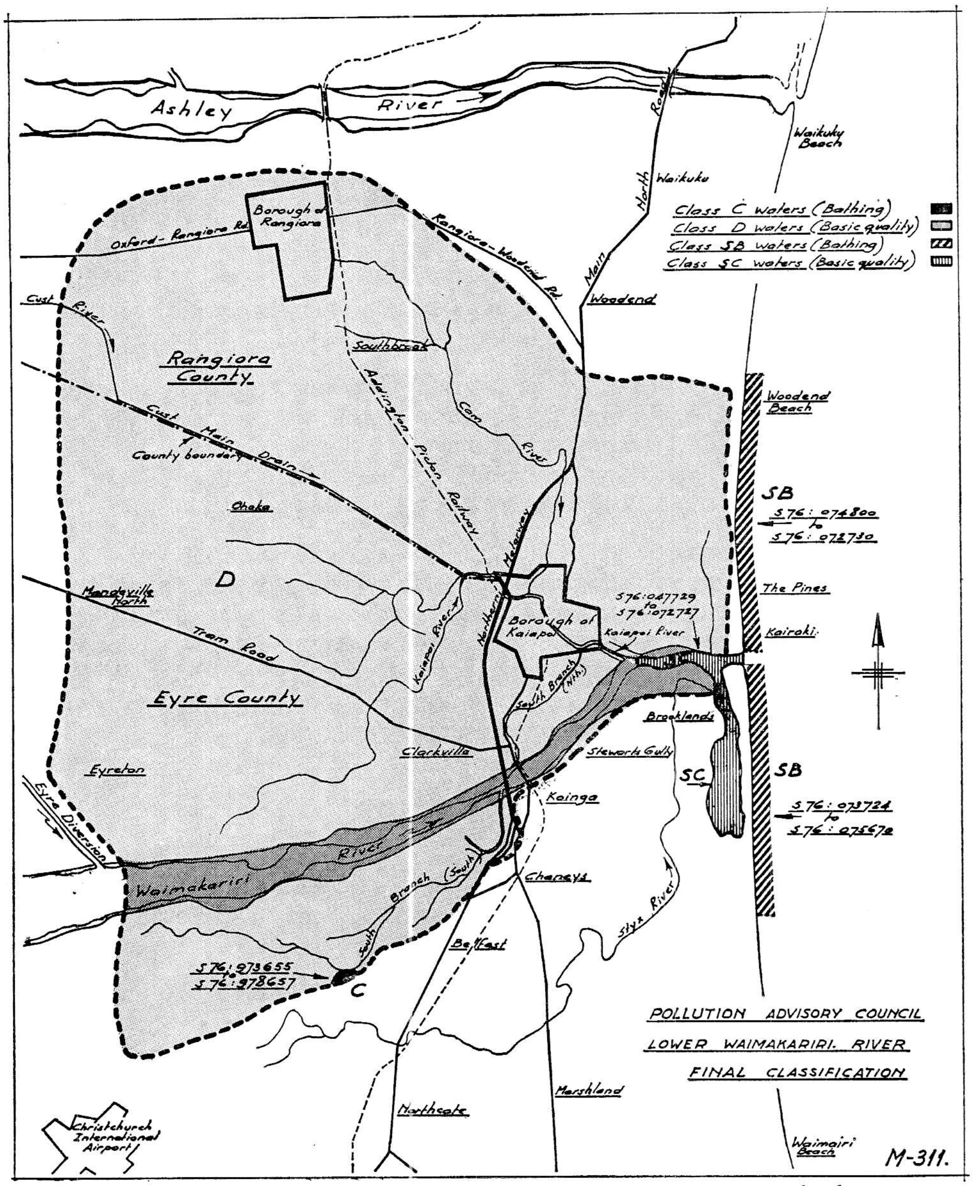
Comparative or corresponding gaugings taken while river flows remain steady. The term simultaneous gaugings used on p. 21 refers to a series of river gaugings that are carried out over a length of river within the time the river traverses that same distance. The time elapsing between flood peaks at the Gorge Bridge and the Highway Bridge is 8 hours, and at low flow this time would be exceeded. The gaugings on 5 February 1970 extended over 6 hrs. 25 mins.

8. *Stage:*

Gauge height, or river level above a datum.

9. *Stage Discharge Curve, or Rating Curve:*

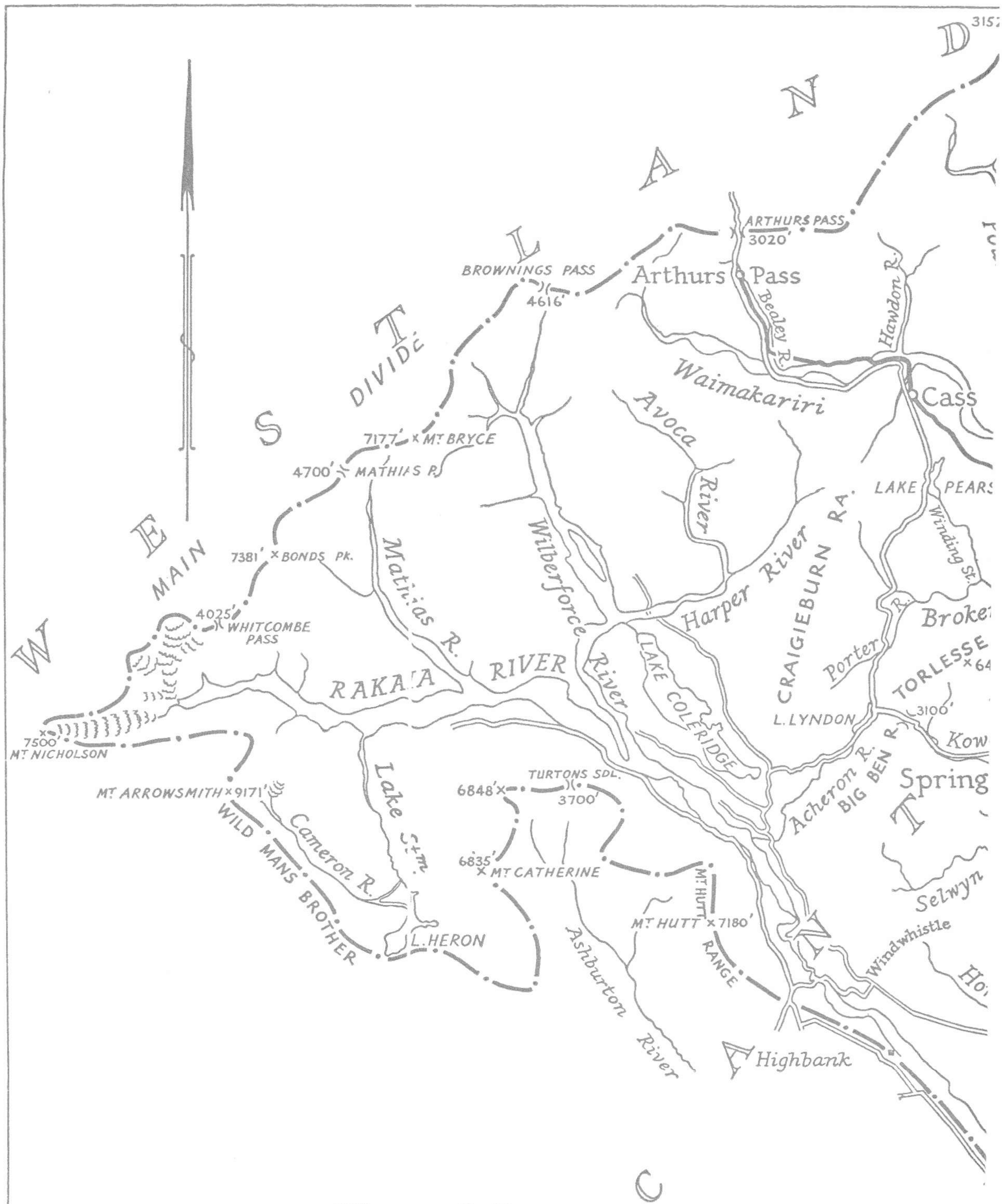
Graph showing the variation of river flow with gauge height. In this report river flow is measured in cubic feet per second or cusecs, and the gauge height in feet.



By permission of the Department of Lands and Survey, New Zealand

CLASSIFICATION OF WATERS

(see p. 23)



Plan of the
NORTH CANTERBURY CATCHMENT DISTRICT

DISTRICT BOUNDARY thus : (as at 1/6/1970)

RAILWAYS : ROADS :

Scale of Miles 10 5 0 10

Drawn by Lands & Survey Dept. Christchurch. 1951.